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PAST AND FUTURE FRESH WATER USE IN THE UNITED STATES

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PAST AND FUTURE FRESH WATER USE IN THE UNITED STATES

Introduction

Offstream water use in the United States has increased over ten-fold during the twentieth century in response to tremendous population and economic growth. Further rapid growth in population and income is almost certain to occur, placing additional demands on water supplies. As withdrawals have increased, more water has been consumed, leaving less instream flow. Instream flows have dropped at the same time as new instream uses have been found by scientists studying the needs of aquatic plants and wildlife and the hydro-geologic requirements of river channels themselves, and as rising incomes and urbanization have intensified calls for maintaining water-based recreation opportunities and protecting water quality (Gullilan and Brown, 1997). All these changes amplify the importance of examining the future adequacy of the nation's water supply. As Congress recognized when it passed the Forest and Rangeland Renewable Resources Planning Act in 1974 (requiring the Forest Service to periodically assess anticipated resource supply and demand conditions), with sufficient forethought necessary adjustments may be anticipated and perhaps facilitated, and unnecessary costs may be avoided.

The adequacy of the water supply depends on how water availability compares with demands for its use. Microeconomics offers one structure for studying the adequacy of a water supply. In economic terms, "demand" and "supply" refer to price-quantity relations. Water use could theoretically be modeled by solving for the equilibrium point of the demand and supply functions for water. However, such functions are very difficult to

specify, especially for all water uses and for large geographic regions containing numerous market areas. Thus, an economic model was not adopted for this study, and "demand" and "supply" are not used herein to refer to formal economic demand and supply functions. Rather, a more modest approach was adopted wherein demand refers to quantity requested and supply to water availability. This quantity-based approach leaves the effect of price unspecified but not avoided; because water and the resources needed to manage it are all scarce, prices affect both the quantity of water requested and the amount available for use. In what follows, the implicit role of price must be remembered.

The supply of water depends on climate and physiography, and on water management infrastructure. The potential for climate change has become a serious concern, but little agreement exists about the effects of climate change on water availability in specific basins (Mahlman, 1997). In light of this uncertainty, a constant climate is assumed for this study. Water management infrastructure (especially dams, canals, and ground water pumping facilities) has greatly expanded the availability of useable water. However, it is generally acknowledged that relatively few opportunities remain, especially in drier regions, for expanding such facilities. Further, because of concern over environmental impacts, proposed new developments are carefully scrutinized. In addition, as sedimentation decreases reservoir storage capacity and as pumping lowers ground water tables, many existing facilities are slowly losing their utility. The additional water development that does occur may merely compensate for these losses. Thus, on balance, the assumption of constant average annual total supply is probably reasonable for most parts of the United States. Assuming constant supply, adequacy depends on the rate of change in demand; the faster demands increase, the sooner supply becomes inadequate

to meet all demands, and thus the sooner that changes in law and public policy— to facilitate or encourage trades, conservation, and other water-saving adjustments—must be contemplated.

Demand for water differs by region. Arid areas have higher demands than do humid areas, all else equal. And within a region of homogeneous weather, demands will differ geographically depending on population, availability of arable land, reliance on thermoelectric electricity, and other factors. The many potential differences among geographic areas suggest that demand for water should be studied at the smallest geographical scale possible. However, isolated small-scale studies, often performed using different variables or methods, do not lend themselves to broad-scale conclusions about regional or national trends.

The objective of this paper is to characterize past and future water use in the entire United States, making a broad-scale approach essential. A national perspective is first adopted in order to present a basic understanding of water use trends. Then water use is described for large, relatively homogeneous regions of the U.S. in order to capture the major regional differences.

Large scale projections of water use in the United States have been attempted several times: in 1961 by the Senate Select Committee on National Water Resources, in 1971 by Wollman and Bonem for Resources for the Future, in 1968 and 1978 by the Water Resources Council, in 1973 by the National Water Commission, and in 1989 by Guldin of the U.S. Forest Service. However, comparisons of these forecasts have consistently found large differences among them in projected water use, as well as large discrepancies between projected and actual water use (Viessman and DeMoncada, 1980; Osborn,

Schefter, and Shabman, 1986; and Guldin, 1989). These large differences highlight the dangers of extrapolation and of forecasting without a detailed understanding of the determinants of water use (Shabman, 1990). And to forecast water use, knowing what the determinants are is only the first step, for once they are identified, they must be accurately forecasted in order to forecast water use.

Guessing about future water use is like most other attempts to divine the future: the only thing we are quite sure of is that the future won't turn out as we expect. Accurate forecasts of future water use are not possible because we know too little about future technological and economic conditions. Thus, we must lower our expectations. What is possible is to project what will happen to water use if recent past trends in the factors that affect water use remain in effect. Such projections—estimates of future possibilities based on projecting past trends—offer a starting point for considering possible adjustments in water prices, management facilities, and institutions. This study will emphasize projections based on the major known water use determinants—population, income, electric energy production, irrigated acreage—in light of information on 1960–1995 trends in water use efficiency. Recognizing the difficulty of forecasting, the overall approach taken here is to minimize complexity so that the underlying assumptions are relatively few and their impact on the results is transparent.

Large Scale Water Use Data

Except for some early estimates of water use from the Census Bureau, this report relies exclusively on water use data from the United States Geological Survey (USGS). The USGS has estimated the nation's water use at five-year intervals since 1950. These

periodic reports, issued as the following USGS circulars, represent the only consistent effort to document water use for the entire nation: MacKichan (1951, 1957), MacKichan and Kammerer (1961), Murray (1968), Murray and Reeves (1972, 1977), and Solley et al. (1983, 1988, 1993). They cover *instream* use at hydroelectric plants; *withdrawals* for delivery to offstream locations such as farms and cities; and *consumptive use,* which is the portion of a withdrawal that evaporates, transpires, or is incorporated into an end product, thus becoming unavailable for use by others within the basin. The portion of withdrawal that is not consumptively used either returns to the stream (called return flow) or contributes to ground water storage. Of the offstream measures, the 1950 and 1955 circulars estimated only water withdrawal, but since 1960 both withdrawal and consumptive use have been estimated. Because of an interest in both withdrawal and consumptive use, this paper will utilize the data found in the USGS circulars since 1960. Including the most recent data, for 1995, yields estimates for eight separate years covering a 35-year span.

The USGS has estimated water use from three principal sources: ground water, fresh surface water, and saline surface water. This report focuses on fresh water. Unless stated otherwise, withdrawals and consumptive use are presented for the combination of ground and surface water.

Since 1955, the USGS circulars have summarized water use for the nation's major watersheds or large areas of contiguous coastal watersheds, called *water resource regions* (WRRs) (Water Resources Council, 1978). Prior to 1970, the circulars aggregated data from what are now the Texas-Gulf region and the Rio Grande region (WRRs 12 and 13) into the "Western Gulf" region, and combined the Upper and Lower Colorado regions (WRRs 14 and

15) into the "Colorado" region. In order to have consistent regions for all years, the 1960 and 1965 data for these two larger regions were allocated to their respective WRRs based on the proportions of population at that time that resided in the separate WRRs.

Water use will be summarized herein first for the United States as a whole, then for six aggregated regions that contain the 18 WRRs within the contiguous 48 states, and finally for the 20 WRRs that comprise the 50 states of the U.S. The aggregated regions are characterized by relatively homogenous precipitation, climate, geography, and water use characteristics—though they unavoidably each contain areas of considerable heterogeneity in at least some variables. Figure 1 shows the six aggregated regions and their respective WRRs.

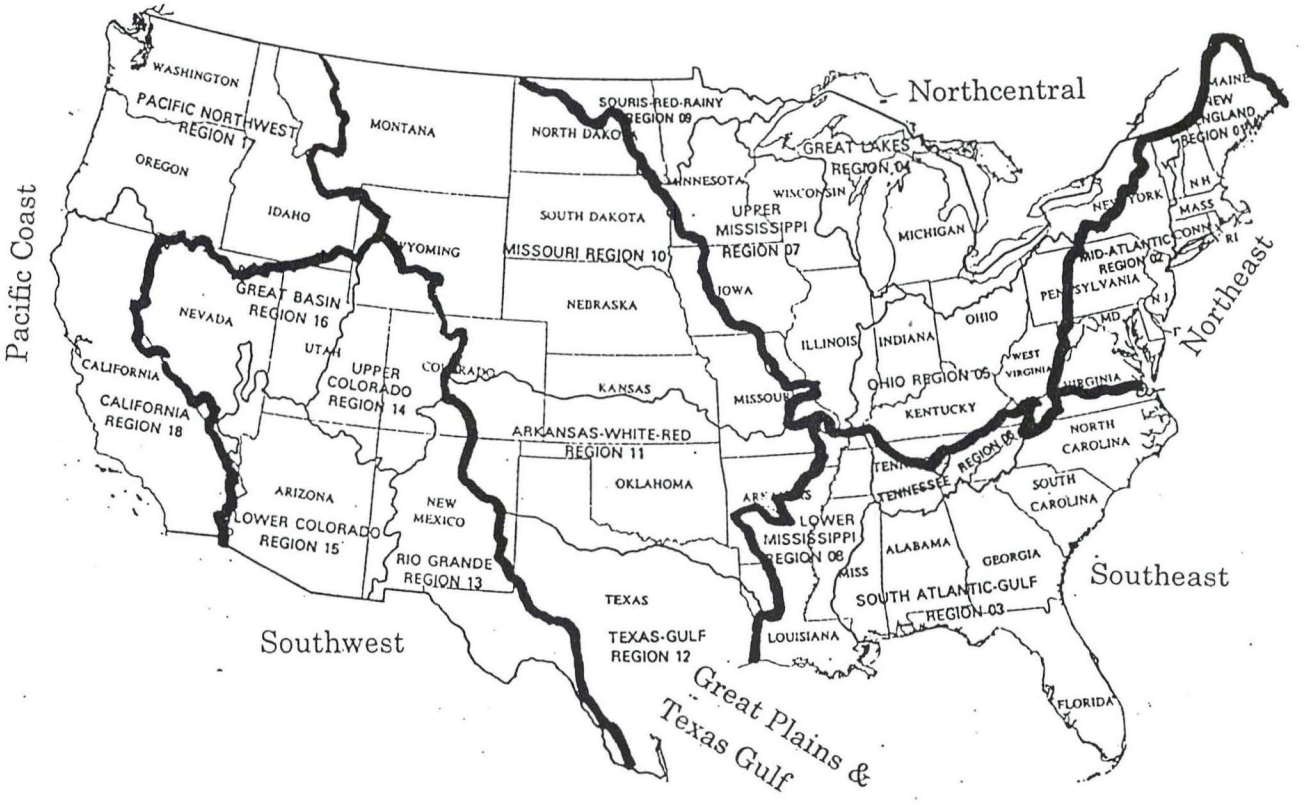

Figure 1. Six Aggregated Regions and Their Eighteen WRRs

The USGS improved its water use data gathering procedure beginning with the 1985 circular. In addition to providing greater funding and more elaborate specifications to field offices collecting the data, the agency also changed some of the categories for which water use was summarized. Most of the changes resulted in more detail, much if it related to reporting of public-supplied water ("public-supplied" refers to delivery by a water supply entity such as a municipality or private water company serving multiple customers). Prior to 1985, deliveries from public supply to industrial and commercial users were grouped together, and deliveries from public supply to domestic and public use were grouped together (the "public" in "domestic and public" refers to governmental office use, public parks, and fire fighting). Also, prior to 1985, mining and self-supplied commercial uses were grouped with self-supplied industrial. After 1985, public-supplied domestic, mining, self-supplied commercial, public-supplied commercial, self-supplied industrial, and public-supplied industrial were all presented as separate categories. Categories that were consistently separate from 1960 to 1995 were self-supplied domestic (rural), livestock, self-supplied thermoelectric, and irrigation. In order to maintain consistent categories for the 1960-95 period, the following categories were chosen:

1. Livestock (only self-supplied)
2. Domestic & public (public- and self-supplied)
3. Industrial & commercial (public- and self-supplied) including mining
4. Thermoelectric cooling (only self-supplied)
5. Irrigation (only self-supplied)
6. Hydroelectric.

Water use efficiencies were computed using the USGS water use data and data on basic water use determinants. A ratio of the determinant to its respective quantity of water withdrawn was computed for each category of use. Total population was used as the basic determinant of livestock and of domestic & public water use. Historical population data were taken from the Bureau of the Census for the years 1960-1990 with the exception of the estimate for 1965, which was never calculated by the Census Bureau and was obtained from the Bureau of Economic Analysis (1992). Population projections through 2040 for the U.S. as a whole were obtained from the Census Bureau (1996). These projections were disaggregated to the state level using projected proportions from the Bureau of Economic Analysis (1995); these state-level projections were then disaggregated to the county level based on the distribution of state population to counties in 1990. Past number of households, also used in computing domestic & public withdrawal, was taken from Census records. The determinant of industrial & commercial water use was total personal income; historical data and projections for this variable were obtained from the Bureau of Economic Analysis (1992 and 1993). All historical data and projections on population and income were available or estimated by county; county figures were then aggregated to WRRs using the county allocations of the Water Resources Council's Assessment Sub-areas (Water Resources Council, 1978). Electricity production was used as the basic determinant of water use at thermoelectric plants; historical data by WRR were taken from the USGS water use circulars. Total irrigated acres was used as the determinant for irrigation water use; historical data by WRR were obtained from the USGS circulars. Projections of future electricity production and irrigated acres were made especially for this study.

The USGS water withdrawal estimates were sometimes based on assumed relations with other, more easily measured variables, such as population or irrigated acres, rather than on actual measures of water diversion or delivery. The degree of reliance on assumed relations of withdrawal to other variables varied by water use category, by USGS state office, and by year (with estimates in more recent years less likely to rely on assumptions). Any such reliance precludes independent efforts using the USGS data to discover what factors affected water use. Thus, only to the extent that the assumed relations were accurately specified do the USGS data provide a basis for describing the relations of past use to factors affecting that use and for projecting future water use.

Past Fresh Water Use in the United States

This section briefly describes water use for 1995, then depicts trends over the twentieth century, and finally looks in more detail at trends for the period 1960 to 1995, all for the U.S as a whole. The subsequent major section presents use estimates for the period 1960 to 2040, first for the U.S. as a whole and then for regions within the U.S.

Recent Water Use

USGS water use data for 1995 indicate that, for the U. S. as a whole, hydroelectric plants used 3041 billion gallons per day (bgd)—nine times the sum of all offstream withdrawals combined.

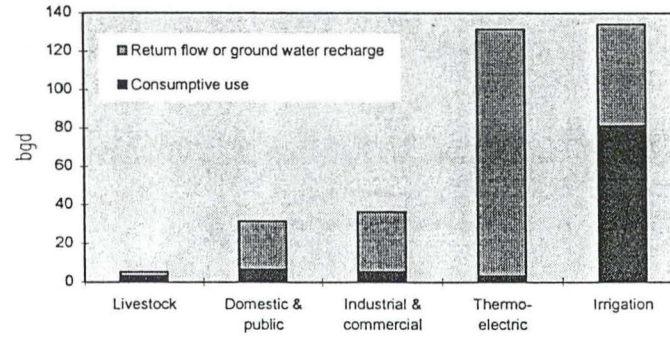

Figure 2. 1995 U.S. withdrawals

The great majority of this use occurs instream (although not without disruptions to the aquatic environment). Looking at offstream use only, withdrawals (the sum of consumptive use and return flow/ground water recharge in Figure 2) totaled 340 bgd. The five categories of water use in Figure 2 fall into three groups. The first group consists of the two largest users, agricultural irrigation and thermoelectric cooling, which each withdrew about 130 bgd. The second group consists of domestic & public use and industrial & commercial use, which each withdrew about 35 bgd. The fifth use, livestock, withdrew only about 5 bgd (although it must be remembered that much of U.S. irrigation is used to produce feed grains and forage for livestock). Thus, the portion of water use that most citizens think of when they contemplate water use—the domestic & public category—accounts for only 10 percent of total withdrawal.

Consumptive use in 1995 totaled 100 bgd, or 29 percent of withdrawal (Figure 2). Irrigation consumptively used 81 bgd. Consumptive use of the other four categories ranged from 3 bgd for livestock and for thermoelectric plants to 7 bgd for domestic & public use. The portion of withdrawal that was consumptively used was about 60 percent for irrigation and for livestock, 21 percent for domestic & public use, 15 percent for industrial & commercial use, and 3 percent for thermoelectric cooling. Ground water pumping contributed 22 percent of total withdrawal.

Trends over the Twentieth Century

Growth in total U.S. withdrawals during the twentieth century has, until recently, consistently out-paced population growth (Figure 3; Bureau of the Census, 1976; Council on Environmental Quality, 1989; USGS circulars). The changes in these two variables fall into three distinct periods: before the Second World War, after that war through 1980, and since 1980. From 1900 to 1940, population increased by roughly 1.7 million persons per year while withdrawals increased by about 2.4 bgd per year. From 1950 to 1980, population increased by about 2.4 million persons per year while withdrawals increased by about 5.7 bgd per year. After 1980, total withdrawals dropped (and then leveled off, as seen below), but population continued to rise. The full change from 1900 to 1990 translates into an annual increase of 1.2 percent for population and 2.4 percent for withdrawal.

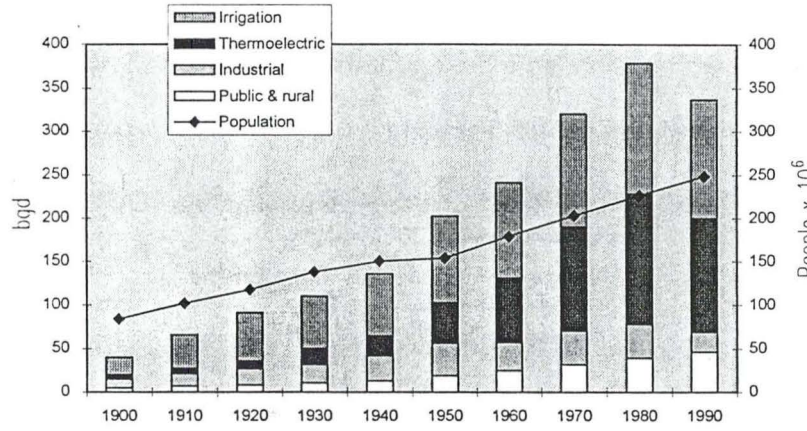

Figure 3. U.S. withdrawal and population, 1900-1990

These differences in rate of change have, of course, increased per capita withdrawals. Total withdrawals per capita increased by nearly a factor of four, from 476 gallons per day in 1900 to 1388 gallons per day in 1990 (Figure

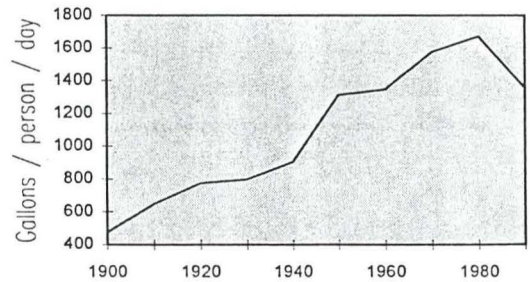

Figure 4. Total withdrawal per capita

4).

The dramatic increase in withdrawals during this century has been largely attributable to increases for irrigation and thermoelectric cooling, which together account for 83 percent of the total withdrawal increase from 1900 to 1990. Over this 90-year period, public (domestic, commercial, and industrial) plus rural (domestic and livestock) withdrawals remained at roughly 12 percent of total withdrawals, self-supplied industrial withdrawals dropped from 25 to 6 percent of total, irrigation withdrawals dropped from 50 to 40 percent of total, and thermoelectric cooling withdrawals increased from 12 to 41 percent of total.

Trends Since 1960

Figure 3 shows a striking change in 1990, when total withdrawals dropped for the first time in the century. Obviously, as that figure shows, the drop was not related to population trends. Figure 5, which presents withdrawals at five-year intervals since 1960 based on the USGS water use circulars, shows that the drop first occurred in 1985, and that it is attributable to the top three categories: irrigation, thermoelectric, and industrial & commercial. Solley et al. (1988) suggested that the drop in 1985 was due partly to (1) above average rainfall that year, which lessened the need for irrigation withdrawals, (2) an economic slowdown

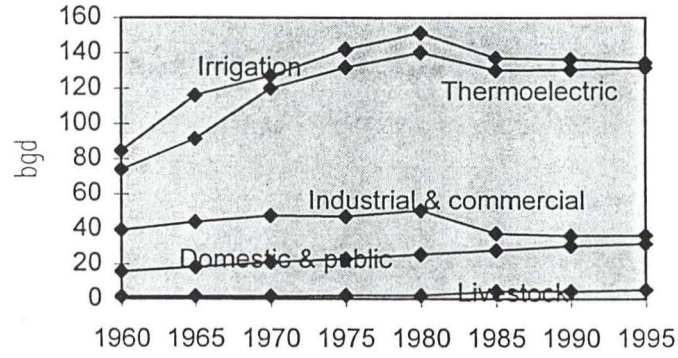

Figure 5. U.S. withdrawals by use category, 1960-1995

and lower commodity prices, (3) higher pumping costs as lifts had continued to increase, and 4) improved efficiency in water use. Solley et al. also suggested, however, that the drop in 1985 was partially attributable to the improved process for amassing the water use data that was initiated by the USGS for the 1985 report, and concluded that earlier estimates may have been too high. A further factor, most important for irrigation, is the subsidence of the era of large-scale, federally-funded water development. Dam construction continues to increase the available supply of water, but the rate of change has greatly diminished after peaking during the 1960s (Figure 6; Army Corps of Engineers and Federal Emergency Management Agency, 1992).

The fact that the three major uses changed little between 1985 and 1995, although rainfall in 1990 was below that in 1985 and economic conditions had improved, suggests that rainfall and general economic conditions did not play

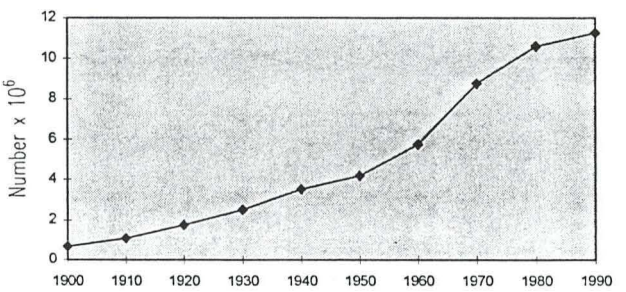

Figure 6. Cumulative number of reservoirs in the U.S. with at least 1000 acre-feet of storage

deciding roles in the dramatic 1985 drop in withdrawals. Although higher pumping costs, improving efficiency of water use, and the waning of the dam construction era undoubtedly contributed to the 1985 drop, such factors have had a gradual and continuing influence over many years and thus are unlikely to have been wholly responsible for the sharp 1985 drop. Thus, the change in the USGS's estimation procedure appears to have played a significant role in the reported 1985 drop in withdrawals. This possibility highlights the importance of focusing on long-term trends rather than short-term shifts when using the water use data.

Consumptive use also steadily increased from 1960 to 1980, followed by a drop in 1985. Consumptive use in irrigated agriculture has dwarfed consumptive use in the other categories for the entire 35-year period (Figure 7). Consumptive use in the other categories has, as a group, been quite constant since 1980, but has climbed again in agriculture (Figure 7).

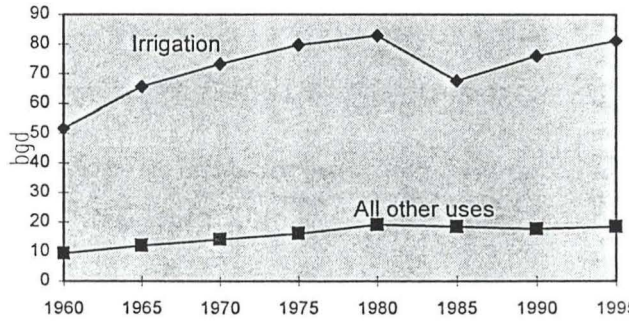

Figure 7. Consumptive use, 1960-1995

A closer look at consumptive use in the other uses (Figure 8) indicates that what was the fastest growing category, thermoelectric, has leveled off, as has industrial & commercial consumptive use, but consumptive use in domestic & public and livestock uses continues to climb.

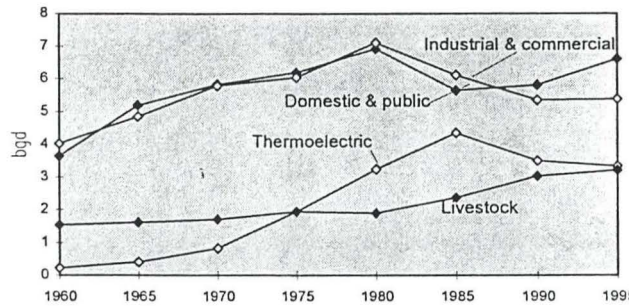

Figure 8. Consumptive use, lessor categories

The proportion of total withdrawal taken from ground water has remained quite stable, ranging from 21 to 24 percent since 1960; it began at 22 percent in 1960, reached its peak of 24 percent in 1975, and has varied from 22 to 23 percent since then. More detail on ground water is presented in a later section.

The following subsections discuss trends in withdrawals for each of the five water use categories shown in Figure 5, beginning with the smallest use category, livestock, and working up to the largest, irrigation. Then trends in hydroelectric water use are briefly described.

Livestock. The USGS's livestock water use category consisted of use by terrestrial animals (or "stock," principally cattle, hogs, sheep, and poultry) until 1985 when "animal specialties" (consisting largely of aquaculture, or fish farming) were moved from the industrial to the livestock category. Once the ponds are established, water is needed at fish farms to maintain a minimum pond level.

Use by terrestrial animals has been estimated by the USGS largely based on numbers of animals served, with different animal species assigned their respective average water requirements. Use of water at fish farms was typically estimated based on pond area and estimates of evaporation and seepage. Withdrawals for the livestock category for the U.S. as a whole gradually

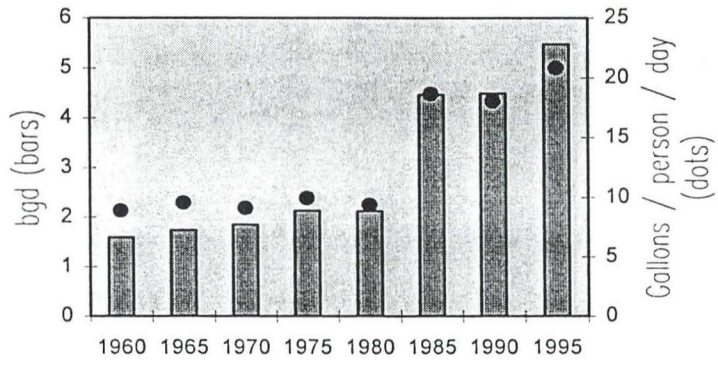

Figure 9. Livestock withdrawal (total and per-person)

increased from 1960 to 1980 in response to increasing animal numbers, then more than doubled in 1985 when animal specialties were added (bars in Figure 9).

Estimates of future stock numbers are not available, so using animal numbers as the determinant of stock water use was not promising. However, human population may serve as a determinant based on the logic that, given constant consumer tastes, meat and egg consumption will vary roughly with the consumer population. Figure 10 shows total and per-person withdrawals for stock (note that withdrawals for stock and for animal specialties were not separated in the 1985 USGS circular, so that datum is missing in the figure). Withdrawal per person has remained quite constant over the past 35 years, ranging between 9 to 10 gallons per day (dots in Figure 10).

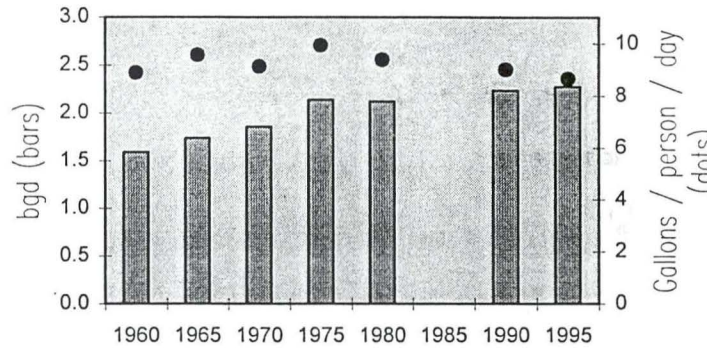

Figure 10. Stock withdrawal (total and per-person)

Adding water use for animal specialties complicates the picture, raising withdrawal per person to from 18 to 21 gallons per day since 1985 (dots in Figure 9). The 3-gallon per-person per-day change from 1990 to 1995 is totally attributable to increased water use by aquaculture, suggesting that use of water per person in aquaculture may be growing.

Domestic & public use. Total U.S. withdrawals for domestic & public water use (public uses and losses are about 15 percent of total domestic & public withdrawals) consistently increased during the 1960-1995 period, rising from 16 bgd in 1960 to about 30 bgd in 1995 (Figure 5). The continued rise after 1985 was in contrast to the other three

major uses, which all reversed the prior upward trend and dropped considerably (Figure 5). One possible reason for this continued rise, as compared to the trend reversals of the other uses, is that domestic & public uses are relatively unresponsive to economic conditions. That is, the demand for domestic water is relatively inelastic to price (Diaz and Brown, 1997, chapter 2), partly because domestic uses are highly valued, to some extent essential, and require little of a household's or municipality's budget. Another reason may be that the USGS estimated domestic & public water use partially based on estimates of population.

The rise in domestic & public withdrawal was primarily caused by population growth, but population increase is not the whole story, for, as seen in the light bars of Figure 11, per capita domestic & public withdrawal also steadily increased, from 89 to 122 gallons per day over the 35-year period. This increasing per capita water use may be largely attributable to a decrease in average household size (Schefter, 1990). As shown by the dots in Figure 11, people per household (i.e., per occupied housing unit) decreased from about 3.4 to 2.7 during the 35-year period. The decrease in household size may be due to various demographic trends such as increasing longevity, decreasing fertility rate, increasing divorce rate, and increasing real income. A certain minimum level of water use per

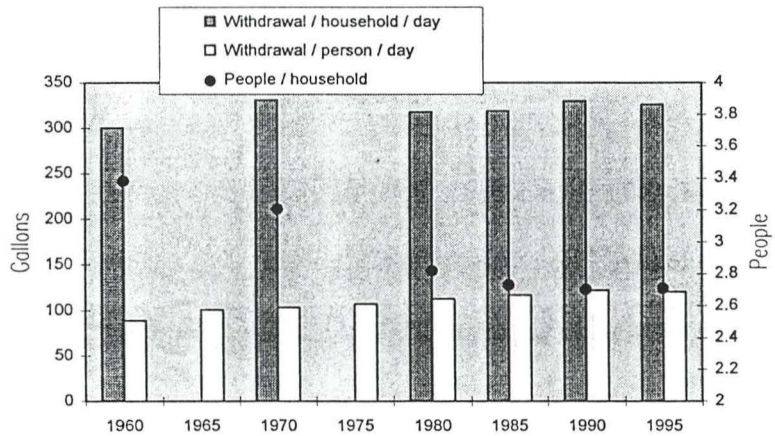

Figure 11. Domestic & public withdrawal

household, especially for lawn and garden watering, is largely unrelated to household size, causing per capita use to rise as household size drops.

Other factors probably contributing to the increase in water use per capita include the conversion of older or rural households to complete plumbing, and an increase in use of water-using appliances such dishwashers, washing machines, swimming pools, and lawn sprinkler systems. These changes are consistent with the increasing real incomes and decreasing real domestic water prices that were experienced in many areas of the U.S. over the past 30 years (Schefter, 1990).

To the extent that the increase in domestic withdrawal per capita was caused by conversion to complete plumbing and use of more water-using appliances, we would expect withdrawal per household to also have risen. However, the record here is less than clear. Withdrawal per household grew from about 300 gallons per day in 1960 to 326 in 1995, but two estimates within the period (331 in 1970 and 330 in 1990) are slightly higher than the 1995 estimate (dark bars in Figure 11). The overall 35-year record suggests an increase, but the 1970 estimate, especially, sheds doubt on the trend. (Note that the 1970 data point is open to question; examination of trends in number of households versus population shows that the 1970 estimate of number of households is questionably low.)

The drop in people per household has been leveling off, withdrawal per person was constant from 1990 to 1995, and withdrawal per household dropped from 1990 to 1995 (Figure 11), but it may be too soon to proclaim an end to the trend of increasing domestic use per capita.

Industrial & commercial use. Total U.S. industrial & commercial withdrawals show a gradual rise from 1960 to 1980, then the sharp decrease in 1985 discussed above

(Figure 5). Only about 2.3 of the 13 bgd drop from 1980 to 1985 is attributable to moving animal specialties to the livestock water use category. Since 1985, total withdrawals have remained at about 36 bgd.

Because of the great variety of outputs of the industrial and commercial sectors, relating water use to units of physical output was unrealistic. Instead, an economic measure of total output—personal income—was used. Withdrawals per dollar of total personal income declined steadily, from 24 gallons in 1960 to 7 gallons in 1995 (bars in Figure 12). The drop in withdrawal per dollar of income is largely attributable to changes in the type and quantity of industrial and commercial outputs, such as a shift from water intensive manufacturing and other heavy industrial activity to service oriented businesses, and to enhanced efficiency of water use. Efficiency has improved in response to such factors as (1) environmental pollution legislation (e.g., the Clean Water Act of 1972 and its amendments), which regulated discharges and thereby encouraged reductions in withdrawals (made possible by modifying production process and recycling withdrawn water), (2) technological advances facilitating recycling, and (3) rising energy and water prices (David, 1990). The most recent data show that the rate of decrease in water withdrawal per dollar of income has slackened somewhat (bars in Figure 12), as expected by David (1990).

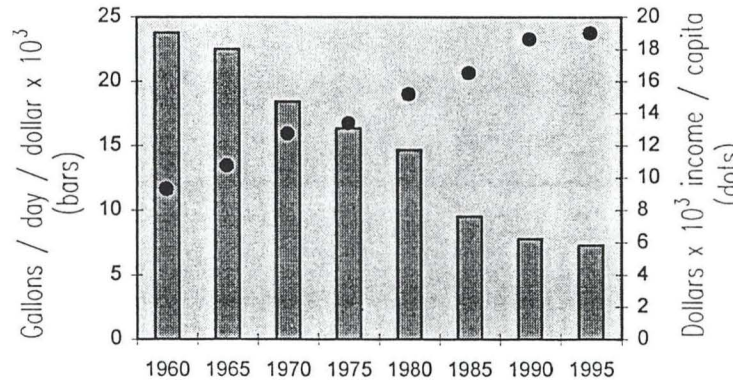

Figure 12. Industrial & commercial withdrawals per dollar (PCI in 1990 dollars)

Thermoelectric use. At thermoelectric power plants (mainly fossil fuel and nuclear plants), water is used principally for condenser and reactor cooling. Fresh water withdrawal increased steadily through 1980, declined substantially in 1985 as mentioned above, and has increased only slightly since then (Figure 5). Withdrawals of salt water, which total roughly 30 percent of recent total water withdrawals at thermoelectric plants and are not shown in Figure 5, have remained quite constant since 1975.

In contrast to the recent leveling off of total withdrawals, production of electricity at thermoelectric plants has continued to rise (dots in Figure 13). Indeed, fresh water withdrawal per kilowatt-hour (kWh) produced has declined steadily, and in 1995 was only 42 percent of its 1960 value (bars Figure 13). This improvement in the efficiency of withdrawals has allowed thermoelectric energy production using fresh water to increase by 322 percent for a mere 78 percent increase in withdrawal. The improved efficiency has occurred partly by greater reuse of withdrawn water; during the 35-year period, consumptive use by thermoelectric plants increased by a factor of 14 (although, as seen in Figure 2, consumptive use is still a small fraction of withdrawal). The latest data indicate a slight decrease compared with earlier years in the rate of decrease in withdrawal per kWh (bars in Figure 13).

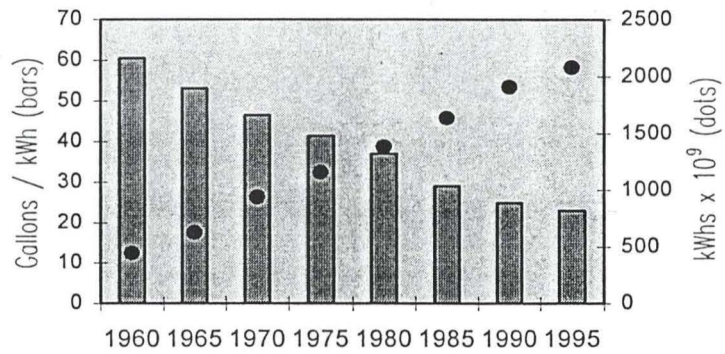

Figure 13. Thermoelectric fresh water withdrawal per kWh

Irrigation. U.S. withdrawals for irrigation steadily increased from 1960 to 1980, then declined in 1985, with additional smaller decreases since then (Figure 5). The decreases since 1985 are not attributable to irrigated acreage changes, as overall irrigated acreage rose from 57.2 million acres in 1985 to 59.2 million acres in 1995 (dots in Figure 14). However, a closer look reveals a geographical shift in irrigated acreage. The arid and semi-arid Western states, where the vast majority of irrigation occurs, are experiencing a decrease in irrigated acreage, which began in the early 1980s, as farmers sell some of their land or water to cities, industries, and rural domestic users, or as pumping costs cause marginal lands to be removed from irrigation. At the same time, farmers in Eastern states are relying more on irrigation water to supplement precipitation during dry times, in order to reduce variability in yields and product quality (Moore et al., 190). This phenomenon is depicted in Figure 15, where the "East" is characterized by WRRs 1-9 and the "West" by WRRs 10-18. The drop in irrigated acreage in Western regions, which tend to use relatively large amounts of water per acre, and rise in irrigated acreage in Eastern regions, which

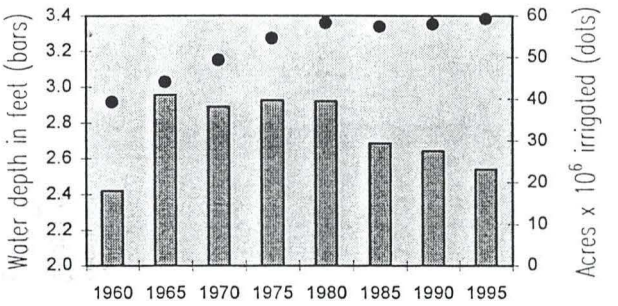

Figure 14. Irrigation withdrawals per irrigated acre

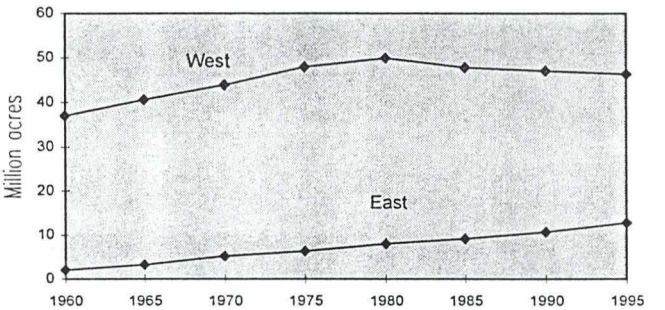

Figure 15. Irrigated acreage

use relatively less water per acre, is partly responsible for the nationwide drop in water application per acre that began in 1985 (bars in Figure 14).

In addition to the acreage shift, the recent downward trend in withdrawal per acre (Figure 14) reflects a direct reduction in water application. As seen in Figure 16, application rates dropped in both the East and the West from 1980 to 1985, and have continued to drop in the West. The recent gradual decrease in application rate in the West may be due to improved irrigation methods. The portion of withdrawal that is consumptively used is one indication irrigation efficiency; improved methods withdraw less water for a given amount of plant transpiration. Consumptive use increased from 47 to 59 percent of total withdrawal in the West from 1985 to 1995. If these estimates are accurate—note that measures of consumptive use rely on a good deal of educated judgment—they partially explain the drop in withdrawal per acre. Improved irrigation efficiency may be a response to such factors as the waning of the era of publicly-funded dam and canal construction, higher prices for water from publicly-funded projects, increasing ground water pumping lifts, and improved irrigation technology (Moore et al., 1990).

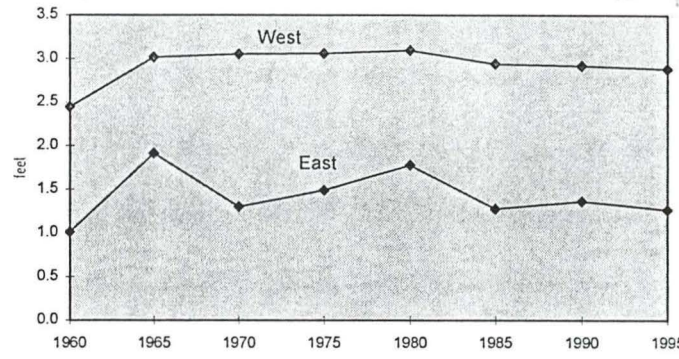

Figure 16. Depth of irrigation withdrawal

To summarize, the recent small declines in total irrigation withdrawals, in the face of an increase in total irrigated acreage, are attributable to the shift in irrigated acreage to

Eastern regions that use less water per acre than do Western regions, and to a drop in withdrawal per acre.

Hydroelectric use. Water use for hydroelectric energy generation increased from about 2×10^{12} gallons per day in 1960 to about 3.3×10^{12} in 1975, but has remained rather constant since then. Total kWhs produced shows the same pattern (dots in Figure 17). Water use per kilowatt-hour produced has remained roughly constant since 1965, averaging 4.1 thousand gallons per kWh (bars in Figure 17).

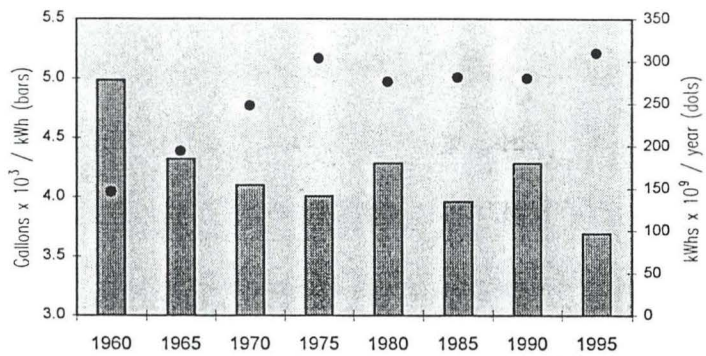

Figure 17. Hydroelectric Use per kWh

Projection of Fresh Water Withdrawals

The following projections of withdrawals are based on estimates of future population and income provided by the Bureau of the Census and Bureau of Economic Analysis, respectively, and on explicit assumptions about rates of change in other factors affecting water use. The explicit assumptions about rates of change in other factors affecting water use were developed specifically for this study. These future rates of change extend past trends, which in most cases have been nonlinear, with the rate of change diminishing in recent years. Extending past trends in other factors affecting water use has thus required in most cases a changing rate of future change, with the rates of change diminishing over time. These rates of future change in other factors affecting water use do

not, it should be noted, reflect a detailed model, economic or otherwise. Rather, they were chosen to maintain continuity of the trend, as will be apparent in subsequent figures.

Computationally, estimates of future levels of other (not population or personal income) factors affecting water use were specified by applying an annual rate of change (i) to the quantity of the prior time period. Quantity (Q) for year n was computed as: $Q_n = Q_{n-1} \bullet (1 + i_n)^t$. When n = 2000, t (time period length in years) = 5, Q_{n-1} was the estimate for 1995 (unless the 1995 estimate showed a distinct shift from 1990, in which case Q_{n-1} was set equal to the mean of the estimates for years 1990 and 1995, and except for irrigation withdrawal per acre, where the 1985–1995 mean was used), and i_n was chosen to maintain continuity of the prior trend. When n = 2010, 2020, 2030, or 2040, t = 10, Q_{n-1} was the projected quantity of the prior time period, and i_n was set equal to $i_{n-1} \bullet (1 + d)^t$, where d was an annual decay of the rate of change, again chosen to maintain continuity of the prior trend. Rates i and d were selected separately for each factor and geographic area (geographic area was national or regional depending on the use category, as described below). Rate of change (i) was positive, negative, or nil depending on the prior trend. Decay (d) was always negative, in keeping with the assumption of diminishing rate of change. The annual rates of change (i) for computation of withdrawals in years 2000 and 2040 are reported below. The results of this approach are seen in subsequent figures.

Projections of National Withdrawals

The following subsections describe the assumptions and water use projections for the five categories of water use discussed above, beginning with the smallest withdrawal category. Figure 18 depicts the projections for all five categories at the national level. In

Figure 18 and in subsequent figures, past withdrawals are depicted by dark bars and future withdrawals are depicted by light bars; similarly, dark dots are used to show past levels of related factors and light dots are used for future levels.

Figure 18. Withdrawal projections for the U.S.
To be located about here

As explained below, population is a factor in the projections of four of the five categories of withdrawal. Population growth has gradually lessened in percentage terms, from 1.3 percent per year in the 1960s, to 1.1 percent in the 1970s, to 0.9 percent in the 1980s. The Census Bureau's middle series projections show U.S. population increasing at annual rates of 1.0 percent during the 1990s, 0.8 percent from 2000 to 2010, and by about 0.7 percent thereafter. This consistent growth rate is apparent in Figure 19 and in the top two graphs of Figure 18.1, which show total U.S. population increasing along a nearly straight line, rising from 263 billion in 1995 to 370 billion in 2040 (a 41 percent increase).

The population projections are based on assumptions about three key factors: life expectancy, fertility, and immigration. The Census Bureau estimates three levels (high, medium, and low) for each factor. The middle series projections use the medium level assumptions for each of the three factors, which are an average life expectancy of 82 years, an average fertility rate of 2.245 births per woman, and a net annual immigration of 820,000 persons (for details, see

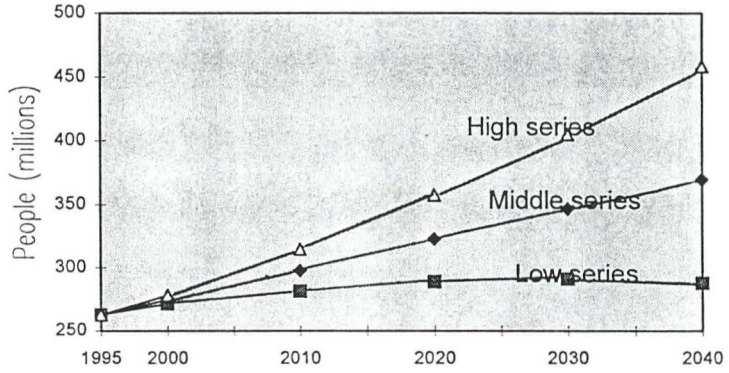

Figure 19. Population projections

U.S. Bureau of the Census, 1996). Likewise, the high series projections use the high level assumptions for each of the three factors, and the low series projections use the low level assumptions for each factor. Intermediate projections (not used herein) can be produced by mixing, for example, low and medium level assumptions for the three factors. The Census Bureau does not present confidence limits about these different estimates. The low and high series can reasonably be considered lower and upper bounds on the middle series. As seen in Figure 19, by the year 2040 there are considerable differences among the series. The low and high series show changes in total population from 1995 to 2040 of 9 percent and 74 percent, respectively, in comparison with the 41 percent increase with the middle series. The following subsections on the five water use categories report results based on the middle population series (Figure 18.1). For comparison with Figure 18.1, estimates using other population series are presented in Figures 18.2 and 18.3, with accompanying text found at the end of this section

Livestock use. Livestock withdrawals per person were assumed to remain constant at the 1995 level of about 21 gallons per day. This assumption allows for shifting tastes within the broad "livestock" category, consisting, as mentioned earlier, largely of beef, pork, lamb, chicken, eggs, and farm-grown fish. The assumption ignores the implication of the 1990 to 1995 increase in withdrawal per capita for aquaculture (Figure 9), which is that additional increases are in store, because a single year's change is assumed to be insufficient to indicate a trend. Total livestock withdrawal in the U.S. is projected to rise from 5.5 bgd in 1995 to 7.7 bgd in 2040 (Figure 18.1).

Domestic & public use. Domestic & public withdrawals were projected based on population and on two major assumptions that together yield projected withdrawal per

person. Those assumptions are about future number of persons per household and future withdrawal per household. Specifically, domestic and public withdrawals were projected as: population • (households / person) • (withdrawal / household).

Persons per household was assumed to drop at a gradually decreasing rate of from 0.1 to 0.07 percent per year over the 1995 to 2040 period (that is, i was set to –0.001 for the period 1996–2000, and to –0.0007 for the period 2031–2040). This projected rate of decrease is lower than it has been in recent years; the annual rate of decrease was 0.5 percent for the 1960s, 1.3 percent for the 1970s, and 0.4 percent for the 1980s (dots in Figure 20). The 0.1–0.07 percent assumption reflects the recent diminishing of the rate of decrease but recognizes that the demographic and economic factors that caused the drop in persons per household over the past 30 years are unlikely to reverse themselves and cause an increase. Based on this assumption, persons per household—which dropped from 3.38 in 1960 to 2.67 in 1995—drops slowly after 1995, reaching 2.58 persons per household in 2040 (dots in Figure 20).

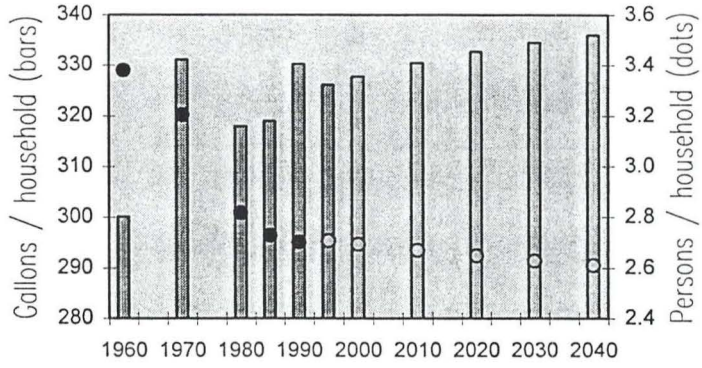

Figure 20. Assumptions about domestic & public withdrawals

Withdrawal per household was assumed to increase at a gradually decreasing rate of from 0.1 to 0.04 percent per year over the 1995 to 2040 period (bars in Figure 20). This projected rate of increase is lower than the rate of increase of the previous 30 years of about 0.3 percent per year on average. The assumption of future increases in withdrawal

per household discounts the importance of the 1970 datum, which contradicts the upward trend in withdrawal per household. The relatively low rate of increase in withdrawal per household projected for the future was based on the expectation that, although technological and economic progress will encourage additional water uses, municipal pricing structures and plumbing fixture ordinances will encourage conservation to largely negate the effect of additional uses on total domestic & public use. Further, it is expected that by now most older or rural houses have already been converted to modern plumbing, thereby largely removing one of the reasons for the past increase in withdrawal per household. Based on this assumption, withdrawal per household—which increased from 300 gallons in 1960 to 326 in 1995—continues increasing at a steady but slow rate, reaching 336 gallons in 2040 (Figure 20).

Given these two assumptions, domestic & public withdrawals are projected to increase from 120 gallons per person per day in 1995 to 129 in 2040. National domestic & public withdrawals are thus projected to increase from 32 bgd in 1995 to 48 in 2040, a 50 percent increase (Figure 18.1).

Industrial & commercial use. Industrial & commercial withdrawals were projected based on estimates of future population and income and assumptions about the rate of change in withdrawal per dollar of income. Specifically, withdrawals were projected as: population • (dollars of income / capita) • (withdrawal / dollar of income).

The BEA projects per capita income, in 1990 dollars, to increase from $19,001 in 1995 to $27,103 in 2040 (dots in Figure 21), which is equivalent to a growth rate of about 0.8 percent per year. Withdrawal per $1000 of income—which dropped at annual rates of 2.5 percent during the 1960s, 2.3 percent during the 1970s, and 6.1 percent during the

1980s (but by only 1 percent from 1990 to 1995)—was assumed to drop at a gradually decreasing rate of from 2 to 1 percent per year over the period from 1995 to to 2040. This assumption continues the past trend of conversion to more efficient processes and greater levels of water recycling. Given this assumption, withdrawal per $1000 of income—which dropped from 24 gallons in 1960 to 7.4 gallons in 1995—continues dropping but at a lower rate, reaching 3.9 gallons in 2040 (bars in Figure 21). Given these two assumptions, total industrial & commercial withdrawals are projected to remain quite stable, changing from 36 bgd in 1995 to 39 in 2040, a 6 percent increase (Figure 18.1). Thus, the decreasing withdrawal per dollar largely compensates for the continued increases in population and per capita income.

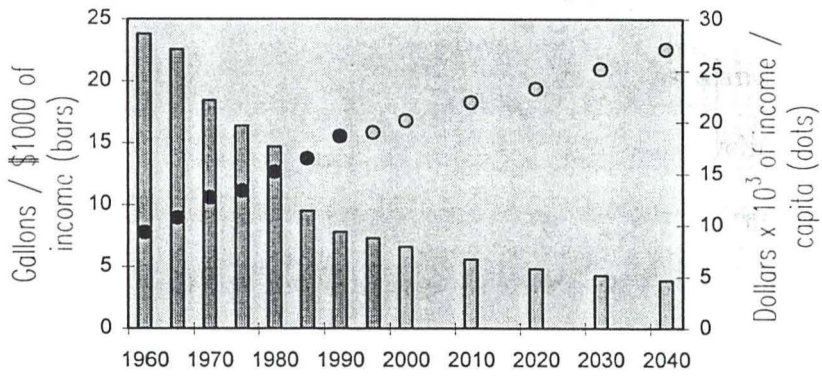

Figure 21. Assumptions about industrial & commercial withdrawals

Thermoelectric cooling. Withdrawals at thermoelectric plants were projected based on estimates of future population and assumptions about the rate of change in energy use per person and in water use per kWh produced, plus an assumption about the proportion of total energy production that will occur at fresh water thermoelectric plants. Specifically, fresh water withdrawal for electric production was estimated as: population • (total kWhs / person) • (fresh water thermoelectric kWhs / total kWhs) • (fresh water withdrawal / fresh water thermoelectric kWh).

Total (thermoelectric plus hydroelectric) energy use per person rose from about 4200 kWh per year in 1960 to about 11,400 in 1995 (dots in Figure 22). In percentage terms, total energy use per person rose at annual rates of 6 percent during the 1960s, 3 percent during the 1970s, and 1.1 percent during the 1980s (but by only 0.4 percent from 1990 to 1995). In keeping with this decreasing trend, future total energy use was assumed to increase by an annual rate decreasing from 0.8 to 0.2 percent over the period 1995 to 2040 (dots in Figure 22), bringing total energy use per person to about 13,900 kWhs per year in 2040. This rate of increase reflects a balance between development of still more energy using conveniences, which would call for greater use per person, and improvements in energy efficiency of all such conveniences, which would call for less.

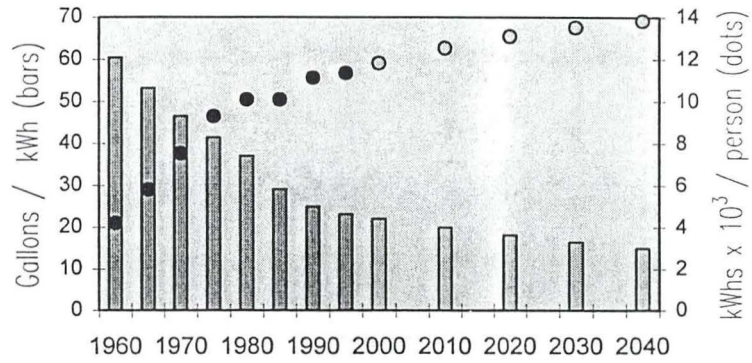

Figure 22. Assumptions about total energy production and thermoelectric plant fresh water withdrawal

Further, it was assumed that generation at hydroelectric plants remained constant at the 1995 level (it has been quite stable since 1975, Figure 17), so that all increases in production occurred at thermoelectric plants; and that the allocation of thermoelectric energy production between fresh water and salt water plants remained constant at the 1995 level (of 70 percent at fresh water plants for the U.S. as a whole). Given these assumptions, use of energy generated at fresh water thermoelectric plants—which increased from 2493 kWhs per person per year in 1960 to 7917 in 1995—was assumed to reach 10,061 kWhs per person per year in 2040. This trend, along with the expected

population increase, produces the increases in total annual energy production at fresh water thermoelectric plants depicted in Figure 18.1 (from $2.1 \bullet 10^{12}$ kWhs in 1995 to $3.7 \bullet 10^{12}$ in 2040).

Water use per kWh produced at thermoelectric plants decreased at annual rates of 2.7 percent from 1960 to 1985, and 2.0 percent from 1985 to 1995. In keeping with this apparent leveling off of the rate of decrease, future water use per kWh was assumed to decrease by from 1 to 0.9 percent per year over the period from 1995 to 2040. Given this rate of decrease, water use per kWh produced at fresh water thermoelectric plants—which decreased from 60 gallons per kWh in 1960 to 23 in 1995—reaches 14 gallons per kWh in 2040 (bars in Figure 22). This trend, along with the increase in production, causes total fresh water withdrawal to rise from 132 bgd in 1995 to 146 in 2040, an 11 percent increase (Figure 18.1). Thus, the decreasing withdrawal per kWh is projected to only partially compensate for the increases in electricity production required to accommodate the growing population and per capita energy use.

Irrigation. Projecting agricultural water use is difficult because so many factors affect agricultural acreage and withdrawal per acre. Irrigation is a lower-valued use of water at the margin than most other uses—most of the recent water trades in the Western states, for example, have been from agriculture to municipal and industrial uses (Saliba, 1987)—so that withdrawals for irrigation are partially a function of water use in the more highly-valued uses. In addition, irrigation water use is a complicated function of population, as increases in population both increase demand for crops and, via urban expansion, decrease availability of irrigable land. Further major factors affecting irrigation include energy prices (via their effect on pumping costs), irrigation technologies,

international markets for agricultural crops, changing tastes for livestock (nearly half of Western irrigated land is used to produce feed and forage for livestock), federal agricultural policies, and instream flow concerns.

In light of the difficulty of accounting for all these factors, a simple approach was adopted for estimating future irrigation withdrawals, which sets withdrawal equal to irrigated acreage • (withdrawal / acre). Future acreage and withdrawal per acre were estimated by extrapolating past trends.

Because some of the factors affecting irrigated acreage vary considerably by region, such as availability of irrigable land and competition for water, acreage was projected at the WRR level and then summed to achieve the national projection. The WRR-level projections of acres are described below in the subsection on WRR projections. This approach yields a projection of U.S. irrigated acreage increasing gradually from 59.2 million acres in 1995 to 62.4 million in 2040 (Figure 18.1).

Withdrawal per acre can vary considerably from year to year at the WRR level because of weather. Thus, time trends of withdrawal per acre at the WRR level are often erratic. To avoid this localized phenomenon, withdrawal per acre was investigated for two large regions: the East and the West. As seen in Figure 16, the decrease in withdrawal per acre in the West has been consistent for 1980–1995, whereas in the East there has been no consistent trend since 1985. In the West, withdrawal per acre—which fell at annual rates of 1 percent from 1980 to 1985 and 0.2 percent from 1985 to 1995—was assumed to continue falling, at a lesser rate of from 0.1 to 0.04 percent for the period 1995 to 2040. Given these rates, withdrawal per acre in the West—which dropped from 3.10 feet in 1980 to 2.88 feet in 1995—drops to 2.80 feet by 2040 (Figure 23). In the East, withdrawal per

acre was assumed to remain constant. These rates of decrease in withdrawal per acre (0 for the East and 0.1 to 0.04 percent per year in the West) were applied to a beginning rate in each WRR set equal to the mean for the years 1985, 1990, and 1995.

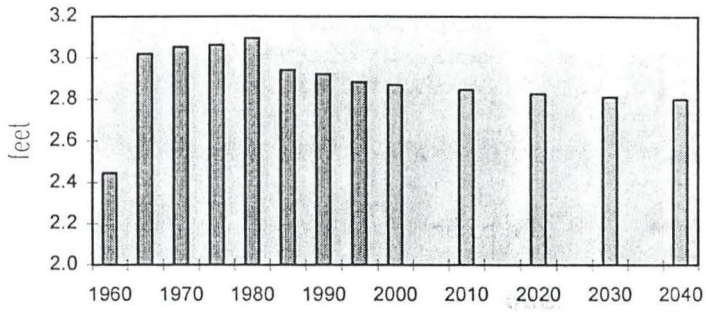

Figure 23. Withdrawal per acre in the West

The aggregation of the results of applying the estimates of acreage and withdrawal per acre at the WRR level yields a slightly decreasing level of total withdrawal for the U.S., from 134 bgd in 1995 to 133 in 2040, as seen in Figure 18.1.

Net change. The graph at the bottom of Figure 18.1 shows the net change in projected total withdrawal in comparison with the 1995 level. Projected total withdrawal increases by 33 bgd (10 percent) from 1995 to 2040. The largest increases are in the domestic & public (16 bgd) and thermoelectric (14 bgd) sectors. Livestock and industrial & commercial each contribute another 2 bgd increase, and irrigation decreases by 1 bgd.

Holding the overall increase within 10 percent of total 1995 withdrawals, in spite of the 41 percent increase in population, is largely attributable to two factors: (1) the improving efficiencies projected for the municipal & industrial and thermoelectric sectors, and (2) the nearly constant total irrigation withdrawal.

Table 1 compares the results using the middle population series with results using the low and high series projections. In contrast to the 10 percent increase in total withdrawals from 1995 to 2040 with the middle series, the low and high series yield changes in withdrawal of –6 and 27 percent, respectively (Table 1, Figures 18.2 and 18.3).

Table 1. National withdrawal projections for alternative population series, expressed as change from 1995 to 2040 (percent change in parentheses).

	Low series	Middle series	High series
Population (millions)	25 (9%)	107 (41%)	195 (74%)
Withdrawal (BGD)			
Livestock	1 (9%)	2 (41%)	4 (75%)
Domestic & public	5 (17%)	16 (50%)	27 (86%)
Ind. & commercial	–6 (–17%)	2 (6%)	12 (32%)
Thermoelectric	–20 (–15%)	14 (11%)	51 (39%)
Irrigation	–1 (–1%)	–1 (–1%)	–1 (–1%)
Total	–22 (–6%)	33 (10%)	93 (27%)

These national projections ignore, of course, the site-specific nature of water availability and use, and therefore the regional variations in net change in total withdrawal. Most importantly, they fail to depict the significant variation in irrigation withdrawals across regions of the country. To gain a more realistic picture of projected water use, projections at the regional scale are next examined.

Projections for Aggregated Regions

Projections for the aggregated regions (regional boundaries are shown in Figure 1) were based on the national-level assumptions about rates of change in withdrawal affecting livestock, domestic & public, industrial & commercial, and thermoelectric use (described above), East/West-level assumptions about rates of change in irrigation withdrawal per acre (also described above), WRR-level assumptions about irrigated acreage (described in the next subsection), and county-level projections of population and

income. The base irrigation withdrawal rates for the aggregated regions are listed in Table 2, along with the assumed rates of change in withdrawal rates for the beginning and end of the 1995–2040 period.

Table 2. Assumptions about future irrigation in the aggregated regions.

Aggregated region	Withdrawal rate		Irrigated acres	
	Mean 1985–95 feet of depth	Annual % change	1995 acres	Annual % change
Northeast	0.93	0	430,670	0.4 to 0.2
Southeast	1.49	0	10,333,000	1.6 to 0.4
Northcentral	0.54	0	1,999,830	1.4 to 0.4
Great Plains & Texas Gulf	1.82	0.1 to 0.04	23,909,230	–0.2 to –0.1
Southwest	4.57	0.1 to 0.04	5,836,680	~0
Pacific Coast	3.88	0.1 to 0.04	16,569,020	–0.5 to –0.1

Also listed in Table 2 are the 1995 irrigated acreages and the assumed rates of change for those acreages, which are averages of the respective WRR amounts. The rates of change each gradually diminish; the rates for the beginning and end of the 1995–2040 period are listed. Irrigated acreage is projected to remain nearly constant at the 1995 level in the Southwest. The projected changes per decade in number of acres irrigated are positive for the Northeast, Southeast, and Northcentral regions, and negative for the Great Plains & Texas Gulf region and the Pacific Coast region. As seen in Figure 24, each of these assumptions in numbers of acres irrigated attempts to extend recent trends.

Figure 24. Withdrawal projections for aggregated regions
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The six parts of Figure 24 depict the projected withdrawals for the six aggregated regions assuming the Census Bureau's middle series of population increases. These results are summarized in Table 3 in terms of the percentage change in withdrawal from 1995 to 2040. All six regions show substantial increases in livestock and domestic & public withdrawal, in keeping with the expected increases in population in all regions. Industrial & commercial withdrawals are projected to decrease slightly in the Northeast and Northcentral regions, and to increase moderately in the other four regions. Regions with the greatest population increases experience the greatest increases in industrial & commercial withdrawal; however, the percentage increases in withdrawal are substantially below the percentage increases in population because of the improving efficiency of industrial & commercial water use.

Table 3. Change in population and withdrawal from 1995 to 2040 for aggregated regions, assuming the Census Bureau's middle population projection series (percent change in parenthesis).

	Northeast		Southeast		North-central		Great Plains & Texas Gulf		Southwest		Pacific Coast	
Population (millions)	17	(31)	25	(51)	20	(30)	14	(41)	7	(64)	22	(52)
Withdrawal (BGD)												
Livestock	0.0	(31)	0.8	(51)	0.1	(30)	0.4	(41)	0.1	(64)	1.0	(52)
Dom. & Pub.	2.4	(40)	3.6	(61)	2.5	(38)	2.5	(51)	1.5	(75)	3.7	(63)
Ind. & Com	−0.2	(−5)	1.3	(14)	−0.5	(−4)	0.3	(8)	0.3	(26)	0.6	(12)
Thermoelect.	0.7	(5)	6.9	(22)	2.5	(4)	2.8	(14)	0.1	(36)	0.8	(132)
Irrigation	−0.0	(−5)	5.9	(46)	0.4	(35)	−2.7	(−7)	0.2	(1)	−4.7	(−8)
Total	3.0	(12)	18.5	(30)	5.0	(6)	3.4	(5)	2.2	(8)	1.5	(2)

Thermoelectric withdrawals increase in all six regions. The percentage increases are small in the two regions with the smallest percentage population increase (the Northeast

and Northcentral regions) and moderate in the Southeast and Great Plains (Table 3). The expected increase in water use efficiency at thermoelectric plants keeps the percentage increase in withdrawals well below the percentage increase in population. The two Western regions are expected to experience the greatest percentage increases in withdrawal (Table 3), but small actual increases. These regions differ from those for the other four because the Western regions currently produce much of their electricity at hydroelectric plants. With the assumption of no future increases in hydroelectric energy production, all of the expected increases in electricity production must be supplied at thermoelectric plants. In the two Western regions, the required increase in production at thermoelectric plants cancels or overwhelms the increase in water use efficiency, resulting in withdrawal increases of 36 and 132 percent, respectively. Finally, irrigation withdrawals differ among regions, reflecting mainly the projected changes in irrigated acreage.

Net change in withdrawal among the six aggregated regions varies from 2 to 30 percent. The two eastern aggregated regions are projected to experience the greatest percentage increases, of 12 percent in the Northeast and 30 percent in the Southeast. Most of the increase in the Northeast is attributable to domestic & public use, whereas in the Southeast the domestic & public, thermoelectric, and agricultural sectors all contribute substantially to the total increase. The increases in total withdrawal in the Northcentral and Great Plains & Texas Gulf aggregated regions (of 6 and 5 percent, respectively) are mostly attributable to domestic & public and thermoelectric uses. The increase in the Southwest and Pacific Coast aggregated regions (of 8 and 2 percent, respectively) are largely attributable to domestic & public uses.

The next section takes a closer look these projections by applying similar methods to the individual WRRs that make up the aggregated regions.

Projections for Water Resource Regions (WRRs)

The national-level assumptions of rates of change in withdrawal affecting future livestock, domestic & public, industrial & commercial, and thermoelectric withdrawals, and the East/West-level assumptions of rates of change in irrigation withdrawal per acre, described above, were applied to all 20 WRRs. The base per-acre withdrawal rates were computed separately for each WRR by averaging the rates for 1985, 1990, and 1995, as described above (except for Alaska, where only the 1990 and 1995 rates were averaged) (Table 4). The East/West rates of change were applied to these averages to yield the future withdrawal rates; the resultant rates for year 2040 are listed in Table 4. For irrigated acreage, WRR-specific assumptions were adopted. The rates of change in irrigated acreage were chosen to extend recent trends. The ranges in rates of change in Table 4 are the annual rates at the beginning and end of the 1995–2040 period. In all cases, the rates of change are assumed to gradually decrease over time. The effects of these assumed rates of change are seen in the plots of irrigated acres in each of the 20 parts of Figure 25.

Figure 25. Withdrawal projections for the WRRs
To be located about here

Table 4. Assumptions about future irrigation in the WRRs.

WRR	Withdrawal rate (feet)		Irrigated acres	
	1985-95 mean	2040	1995	Annual % change
1. New England	1.40	1.40	102,600	0
2. Mid Atlantic	0.84	0.84	328,070	0.5 to 0.2
3. South Atlantic-Gulf	1.37	1.37	3,550,470	1 to 0.3
4. Great Lakes	0.63	0.63	555,840	0.8 to 0.4
5. Ohio	0.46	0.46	555,840	5 to 0.3
6. Tennessee	0.90	0.90	221,970	4 to 0.5
7. Upper Mississippi	0.49	0.49	1,054,360	1 to 0.4
8. Lower Mississippi	1.62	1.62	6,738,910	2 to 0.5
9. Souris-Red-Rainy	0.69	0.69	167,660	1 to 0.4
10. Missouri Basin	2.06	2.05	13,513,690	0
11. Arkansas-White-Red	1.64	1.63	6,116,610	–0.5 to –0.2
12. Texas-Gulf	1.33	1.33	4,278,930	–0.5 to –0.2
13. Rio Grande	4.59	4.57	1,264,100	–0.7 to –0.3
14. Upper Colorado	4.96	4.94	1,709,310	1 to 0.2
15. Lower Colorado	5.06	5.05	1,256,540	0
16. Great Basin	3.87	3.86	1,606,730	–0.5 to –0.2
17. Pacific Northwest	4.44	4.42	7,029,760	–1 to –0.2
18. California	3.44	3.43	9,539,260	–0.2 to –0.1
19. Alaska	0.46	0.46	1,430	0
20. Hawaii	6.60	6.60	135,600	–1 to –0.4

Examination of Figure 25 reveals numerous anomalies, which were not apparent in the aggregated data of Figures 18 and 24. Examples include the following: (1) in WRR 1, livestock withdrawal in 1985 is unusually high; (2) in WRR 5, irrigation withdrawal in

1980 is unusually high; (3) in WRR 7, domestic & public withdrawal in 1970, and industrial & commercial withdrawal in 1980, are unusually high; (4) in WRR 8, industrial & commercial withdrawals in 1970, 1975, and 1980 are unusually high; (5) in WRR 9, industrial & commercial withdrawals in 1975 and 1980 are unusually low; (6) in WRR 13, thermoelectric withdrawals in 1960 and 1965 are unusually high, and industrial & commercial withdrawals in 1980 are unusually low; (7) in WRR 14, livestock, domestic & public, and industrial & commercial withdrawals in 1980 are unusually high, and irrigated acreage in 1970 is unusually low; (8) in WRR 18, thermoelectric withdrawals in 1985 drop precipitously; and (9) in WRR 19, livestock withdrawals in 1985 are unusually high. Explanations for these unusual entries are often difficult to obtain, especially for earlier years. Some of the entries may be errors, but most probably have logical explanations (for example, in WRR 18, the decrease in thermoelectric withdrawal in 1985 is related to a switch from fresh to salt water). The purpose here is not to explain every entry, but rather to look at overall trends. Nevertheless, the anomalies highlight the importance of not placing too much importance on individual data entries.

As seen in Figures 25.1–25.20 and summarized in Table 5, all WRRs show increases in withdrawals for livestock and domestic & public uses, in keeping with the assumptions of increasing population in all regions. On a percentage basis (Table 6), the 1995–2040 increases in livestock and domestic & public withdrawals are most pronounced in the West where the greatest population increases are expected (note that the percentage changes in population are identical to the percentage changes in livestock withdrawal listed in Table 6). Six regions show decreases in withdrawals for industrial & commercial uses (ranging from 1 to 6 percent), despite the expected increases in economic activity in all regions,

Table 5. Change in withdrawal from 1995 to 2040, middle population series (MGD).

	Livestock	D&P	I&C	Thermo.	Irrigation	Total
1. New England	7	515	-18	205	-18	691
2. Mid Atlantic	39	1895	-208	376	-5	2098
3. South Atlantic-Gulf	223	3006	807	4343	919	9298
4. Great Lakes	18	1157	-481	695	79	1469
5. Ohio	43	766	-91	798	85	1601
6. Tennessee	86	207	87	1527	23	1930
7. Upper Mississsippi	84	491	-17	1103	135	1797
8. Lower Mississippi	333	381	73	391	4973	6151
9. Souris-Red-Rainy	5	22	-2	3	51	80
10. Missouri	169	649	51	1309	137	2316
11. Arkansas-White-Red	147	497	85	442	-1597	-425
12. Texas-Gulf	91	1417	150	1068	-1203	1524
13. Rio Grande	17	240	23	3	-1838	-1555
14. Upper Colorado	31	83	13	41	2255	2423
15. Lower Colorado	28	747	145	28	-281	667
16. Great Basin	65	409	123	10	113	721
17. Pacific Northwest	804	953	389	1873	-3266	753
18. California	235	2768	262	111	-1394	1981
19. Alaska	0	35	12	13	0	60
20. Hawaii	5	105	9	15	-55	79

Table 6. Percent change in withdrawal from 1995 to 2040, middle population series.

	Livestock	D&P	I&C	Thermo.	Irrigation	Total
1. New England	38	47	-2	12	-12	19
2. Mid Atlantic	29	38	-6	3	-2	10
3. South Atlantic-Gulf	55	66	17	25	19	29
4. Great Lakes	26	34	-8	3	25	5
5. Ohio	30	39	-2	4	81	5
6. Tennessee	42	51	6	22	48	21
7. Upper Mississsippi	33	42	-1	6	28	8
8. Lower Mississippi	33	42	2	6	61	31
9. Souris-Red-Rainy	26	34	-5	8	58	32
10. Missouri	40	49	6	15	1	6
11. Arkansas-White-Red	37	47	7	11	-17	-3
12. Texas-Gulf	44	54	9	14	-22	9
13. Rio Grande	47	57	13	19	-31	-23
14. Upper Colorado	57	67	20	28	32	33
15. Lower Colorado	70	82	27	45	-4	8
16. Great Basin	75	87	36	41	2	12
17. Pacific Northwest	53	64	14	486	-13	2
18. California	52	62	11	54	-5	5
19. Alaska	54	64	10	43	4	28
20. Hawaii	53	64	7	22	-8	8

Note: Percentage changes in population equal the percentage changes in livestock.

because of the assumed increase in efficiency of industrial & commercial water use. In the other 14 regions, population and per-capita income increases overwhelm the increasing efficiencies of water use to cause projected increases in industrial & commercial withdrawals of from 2 to 36 percent.

Withdrawals for thermoelectric plants increase steady over the 1995–2040 period for all regions. The largest percentage increases occur in regions of greatest population increase and where production at fresh water plants is currently relatively less important (where a large portion of the production occurs at hydroelectric plants or at salt water thermoelectric plants). The very large percentage increase in the Pacific Northwest is attributable to the fact that hydroelectric dams now provide 89 percent of the region's electricity production, a far greater percentage than for any other region. With the assumptions of constant hydroelectric production at the 1995 level and constant proportional allocation of thermoelectric production between fresh and salt water plants, production at fresh water thermoelectric plants must increase substantially to accommodate the required increase in total electric energy production of 87 percent from 1995 to 2040.

Irrigation withdrawals are projected in increase in ten regions, decrease in nine, and remain constant in one (Table 5). Only three regions experience substantial volume increases in withdrawal (the South Atlantic-Gulf, Lower Mississippi, Upper Colorado regions), although in percentage terms several other regions also show substantial increases (Table 6). The changes are largely a function of the assumed irrigated acreage changes, although the changes in application per acre also play a role. Note that the large 1995–2040 increase in Upper Colorado Basin irrigation withdrawal raises irrigation

withdrawal to only slightly above its 1970 level, whereas the increases in the South Atlantic-Gulf and Lower Mississippi regions raise irrigation withdrawal far above past levels.

Changes in total withdrawal are shown in the bottom graphs of the 20 parts of Figure 25 and summarized in the right hand columns of Tables 5 and 6. Only two regions (Arkansas-White-Red and Rio Grande) are expected to experience decreases in total withdrawal from 1995 to 2040. In these regions, large decreases in irrigation withdrawal out weigh increases in the other four categories of water use. Increases in total withdrawal among the other 18 regions range from 2 to 33 percent (Table 6). Total withdrawal increases exceed ten percent in eight regions. These eight regions can be sorted into two groups based on the water use categories to which the increases in total withdrawal are attributable. In five regions (New England, South Atlantic-Gulf, Tennessee, Great Basin, and Alaska; Table 5), the increases are largely attributable to increases in domestic & public and/or thermoelectric use. In the other three regions (Lower Mississippi, Souris-Red-Rainy, and Upper Colorado), the total withdrawal increases are largely attributable irrigation uses.

Effects of withdrawal increases are felt within the region, and perhaps also downstream of the region. Of the eight regions of greatest percentage increase in total withdrawal, outflows from four regions (New England. South Atlantic-Gulf, Lower Mississippi, and Alaska) flow into the sea. Outflows from the Tennessee Region flow into the Mississippi River, and thus are not of overwhelming concern. Outflows from the Souris-Red-Rainy region flow north to Canada in an area where water is quite plentiful [correct?]. The Great Basin region is closed. Thus, only outflows from the Upper Colorado Basin

(WRR 14) are of critical concern to downstream basins. The Upper Colorado Basin is also the region of the largest percentage increase, at 33 percent.

The Colorado River Compact of 1922 limits withdrawals in the Upper Colorado Basin to those that will allow delivery of 8.23 million acre-feet per (maf) per year on average to the Lower Basin (Mac Donnell et al., 1995). Given this century's mean annual virgin flow at the delivery point (Lees Ferry) of about 16.5 maf, and current annual Upper Basin depletions (including reservoir evaporation) of about 4.5 maf, resulting average annual deliveries to the Lower Basin are about 12 maf, far above the Compact requirement (data from Brown et al., 1990, and Harding et al., 1995). With the projected increase in Upper Basin withdrawal of 33 percent (Table 5), and assuming a 50 percent return flow, Upper Basin depletions would increase to 5.2 maf by 2040, leaving deliveries to the Lower Basin of 11.3 maf, which is still well above the Compact requirement.

However, tree ring studies indicate that the long term annual virgin flow at the delivery point is about 13.5 maf (Stockton and Jacoby, 1976), well below the 16.5 mean annual flow of this century, which was amplified by unusually high flows during the century's first three decades. Assuming this lower level of available flow and the projected Upper Basin depletion of 5.2 maf leaves only 8.3 maf per year on average for delivery to the Lower Basin, which is very close to the Compact requirement. Deliveries at this level would have implications for water users in the Lower Colorado Basin (WRR 15) and in Southern California (part of WRR 18). Users in Southern California have historically used much of the surplus water that Upper Basin states have allowed to flow to the Lower Basin. The projected increase in Upper Basin withdrawal (of about 2.3 bgd) is not balanced by projected decreases downstream, as both the Lower Colorado Basin and California

WRRs, are projected to experience increases (of 0.7 and 2 bgd, respectively) (Figures 25.14, 25.15, and 25.18). Thus, given the lower, and more realistic, available water supply in the Colorado River of 13.5 maf per year, users in Southern California will be forced to curtail their use of Colorado River water. This scenario suggests opportunities for trade, lending support for institutional changes that would allow water trades between Upper Basin and Lower Basin states.

Of the seven remaining WRRs of greatest percentage increase in total withdrawal, Alaska is of least concern because water supplies far exceed the relatively low levels of withdrawal in that state. However, the increase in total withdrawal is of considerable concern in the other six regions because of within-region impacts. Although conditions in most of the regions are quite humid, even there water supplies can be strained during dry times. Of course, the impacts will not be felt uniformly across a region. The estimates presented here are statistical averages that are unlikely to apply in any one place. The impacts in individual locations will vary above and below the regional averages depending on local supply and demand characteristics. Further, note that the impacts are not limited to the categories of consumptive use discussed here. Wherever diversions increase, instream flow and surface water quality can be expected to decrease, all else equal.

Sensitivity of Projections to Assumptions About Factors Affecting Water Use

As reported above, assuming the middle population series and the best-guess estimates of all other assumptions, total withdrawals in the U.S. are projected to increase from 340 bgd in 1995 to 373 bgd in 2040, a 10 percent increase. Table 7 repeats the percentage changes from 1995 to 2040 for the middle population series that were presented earlier and also shows the 1995–2040 change assuming the low and high population series. With the low series, total withdrawals actually *drop* by 6 percent for the U.S. as a whole; efficiencies in industrial & commercial and thermoelectric water uses more than compensate for the 9 percent increase in total population from 1995 to 2040. Looking down Table 7 indicates that the decrease in total withdrawal occurs in all WRRs except those where significant increases in irrigation withdrawals are projected. With the high series, total U.S. withdrawals are projected to increase by 27 percent from 1995 to 2040. Increases in total withdrawal are projected for all but the Rio Grande region where the drop in irrigation withdrawal

Table 7. Percent change in total withdrawal from 1995 to 2040 for three Census Bureau population projection series.

Region	Population series		
	Middle	Low	High
United States	10	-6	27
Aggregated region			
Northeast	12	-13	39
Southeast	30	8	55
Northcenteral	6	-18	31
Great Plains & Texas Gulf	5	-7	18
Southwest	8	3	13
Pacific Coast	2	-5	9
Water resource region			
1. New England	19	-8	47
2. Mid Atlantic	10	-15	36
3. South Atlantic-Gulf	29	4	56
4. Great Lakes	5	-20	31
5. Ohio	5	-18	31
6. Tennessee	21	-8	53
7. Upper Mississsippi	8	-16	33
8. Lower Mississippi	31	16	47
9. Souris-Red-Rainy	32	14	51
10. Missouri Basin	6	-2	16
11. Arkansas-White-Red	-3	-14	10
12. Texas-Gulf	9	-10	29
13. Rio Grande	-23	-26	-20
14. Upper Colorado	33	31	34
15. Lower Colorado	8	1	16
16. Great Basin	12	6	18
17. Pacific Northwest	2	-6	12
18. California	5	-1	13
19. Alaska	28	-1	60
20. Hawaii	8	-3	20

outweighs the increases caused by increasing population. The other 19 regions would all see total withdrawals increase by at least 10 percent, with 11 regions experiencing increases of at least 30 percent. Obviously under this high population increase scenario, U.S. water resources would be under extreme pressure, with serious consequences for offstream users, instream flow, and water quality.

Table 8 lists the percent change, from the best guess scenario, in total withdrawal in year 2040 that is caused by a 10 percent change in factors affecting projected water use. For example, the upper left estimate of 6.6 percent indicates that if future U.S. population were 10 percent greater than projected by the Census Bureau's middle series, total withdrawals in year 2040 would be 6.6 percent greater than those indicated in Figure 18.

Table 8. Percent change in total withdrawal from best guess scenario in year 2040 caused by a 10 percent increase in factors affecting water use (the best guess scenarios are presented in Figures 18.1, 24, and 25).

Region	Factor						
	Population	Wd / hh	hh / person	Wd / $ PCI	Wd / kWh	kWh / per.	Acres irrig.
United States	6.6	1.3	1.4	1.0	3.9	4.1	3.6
Aggregated region							
Northeast	10.0	3.0	3.4	1.4	5.4	5.5	0.1
Southeast	7.8	1.2	1.3	1.3	4.8	4.9	2.4
Northcenteral	10.0	1.0	1.1	1.4	7.4	7.6	0.1
Great Plains & Texas Gulf	5.1	1.0	1.1	0.5	3.2	3.3	5.0
Southwest	1.8	1.1	1.2	0.5	0.1	0.1	8.2
Pacific Coast	2.9	1.4	1.5	0.8	0.2	0.3	7.2
Water resource region							
1. New England	9.9	3.7	4.1	1.7	4.3	4.5	0.3
2. Mid Atlantic	9.9	2.9	3.3	1.3	5.6	5.6	0.1
3. South Atlantic-Gulf	8.7	1.8	2.0	1.4	5.3	5.4	1.4
4. Great Lakes	10.4	1.3	1.5	1.6	6.9	7.4	0.1
5. Ohio	10.0	0.9	1.0	1.4	7.6	7.6	0.1
6. Tennessee	10.8	0.6	0.6	1.3	7.8	8.7	0.1
7. Upper Mississsippi	9.8	0.7	0.7	0.9	8.0	8.1	0.2
8. Lower Mississippi	5.0	0.5	0.5	1.2	2.7	2.8	5.0
9. Souris-Red-Rainy	6.0	2.6	2.9	1.2	1.2	1.4	4.2
10. Missouri Basin	3.7	0.5	0.6	0.2	2.6	2.8	6.5
11. Arkansas-White-Red	5.2	1.0	1.1	0.8	2.9	3.0	4.9
12. Texas-Gulf	7.7	2.1	2.3	0.9	4.6	4.6	2.3
13. Rio Grande	1.8	1.3	1.4	0.4	0.0	0.0	8.2
14. Upper Colorado	0.6	0.2	0.2	0.1	0.2	0.2	9.4
15. Lower Colorado	2.9	1.9	2.1	0.8	0.1	0.1	7.1
16. Great Basin	2.3	1.3	1.4	0.7	0.1	0.1	7.7
17. Pacific Northwest	3.8	0.7	0.8	1.0	0.7	1.3	6.9
18. California	2.8	1.9	2.1	0.7	0.1	0.1	7.2
19. Alaska	10.3	3.3	3.6	5.1	1.6	1.9	0.0
20. Hawaii	4.5	2.5	2.7	1.2	0.7	0.8	5.5

The effects of changes in the factors are considered separately, such that each column of the table investigates a single change, with all other factors remaining at their best guess estimates reported in previous sections.

For the U.S. as a whole, a 10 percent increase in population has a larger impact on withdrawals than a 10 percent change in any of the other six factors listed in Table 8. For example, a 10 percent increase in withdrawal per household causes only a 1.3 percent increase in total withdrawal, and a 10 percent increase in kWhs per person causes a 4.1 percent increase in total withdrawal. The relatively large effect of population change is due partially to the fact that population is a variable in projections of withdrawals in four of the five categories of water use; only future irrigation withdrawals were not modeled as a function of population.

Comparison across regions indicates that sensitivity to the various changes in assumptions is greatest in regions where the affected water use accounts for a larger share of total withdrawal. For example, the effect of a percentage increase in withdrawal per household is greatest in the Northeast aggregated region, where domestic & public uses are relatively more important (accounting for 30 percent of total withdrawals in 2040). And the effect of a percentage increase in irrigated acres is greatest in the Southwest and Pacific Coast aggregated regions, where irrigation is more important (accounting for 82 and 72 percent, respectively, of total 2040 withdrawals).

The sensitivity of total withdrawals to 10 percent increases in factors affecting thermoelectric withdrawals is very small in most of the Western regions. In WRRs 13–16, the principal reason for the low sensitivity is the small amount of water withdrawn per kWh produced (withdrawal in these regions tends to be less than 1 gallon per kWh,

whereas in most other regions withdrawal tends to range from 10 to 50 gallons per kWh). In WRRs 18 and 20, the low sensitivity is due mainly to the relatively small amount of electricity that would be produced at fresh water thermoelectric plants (2 percent and 7 percent, respectively). In WRR 17, the low sensitivity is due to the combination of a rather low withdrawal rate (of 8 gallons per kWh) and moderate proportion of total electricity produced at fresh water thermoelectric plants (of 52 percent).

Table 8 shows the effect on total withdrawals of changes in the factors affecting water use, but does not indicate which changes are more or less likely to occur. Of the various factors considered in this report, irrigated acreage is perhaps the most difficult to predict, because it depends on so many factors, some of which (like international trade) are quite volatile. Increasing world-wide food needs, for example, may increase crop prices and lead to increased production by U.S. farmers. In this light, we take a second look at irrigation withdrawals, by examining the effect of removing the future decreases in irrigated acreage assumed for the seven WRRs, all in the Western part of the country, where acreage decreases were projected (Table 4). If irrigated acreage in those seven WRRs were to remain constant at their 1995 levels, instead of dropping as assumed, total withdrawals would be affected as listed in Table 9.

As seen in Table 9, if irrigated acreages in the seven listed WRRs were to remain at their 1995 levels, instead of decreasing as projected (Figure 25), U.S. total withdrawal in 2040 would be 13 percent above the 1995 level rather than 10 percent above. Only in WRR 13 would total withdrawals in 2040 would still be below the 1995 level. In the other five WRRs, withdrawals in 2040 would be substantially (from 5 to 26 percent) above their 1995

levels. Accommodating such increases would require major adjustments in water use and lead to serious conflicts with instream uses as well as with other offstream uses.

Table 9. Net percentage change in withdrawal from 1995 to 2040

Region	Best guess scenario (as depicted in Figures 18 and 25)	With irrigated acreage of the seven WRRs held constant at the 1995 level
United States	10	13
Water resource region		
11. Arkansas-White-Red	–3	5
12. Texas-Gulf	9	13
13. Rio Grande	–23	–9
16. Great Basin	12	26
17. Pacific Northwest	2	19
18. California	5	9
20. Hawaii	8	25

Finally, consider a change in the projected increase in withdrawal per household, which under the best guess scenario increases from 326 gallons per day in 1995 to 336 in 2040. With continued efforts at water conservation, this increase may be avoided. If withdrawals per household were held at the 1995 level through 2040, U.S. domestic & public withdrawals in 2040 would be reduced from 48 bgd with the best guess scenario to 46 bgd, thereby reducing the total 1995–2040 withdrawal increase from 10 percent with the best guess scenario to 9 percent.

Ground Water

Ground water pumping increased consistently in both the East and the West from 1960 to 1980 (Figure 26; the East consists of the Northeast, Southeast, and Northcentral aggregated regions, the West of the remaining three). The drop in 1985 indicted in Figure 26 in both the East and the West is related to the overall drop in withdrawal (Figure 5), and could be partly due to the change in data gathering procedure initiated by the USGS for the 1985 circular, as noted above. Since 1985, ground water pumping in the West has been quite stable, though it has been increasing in the East.

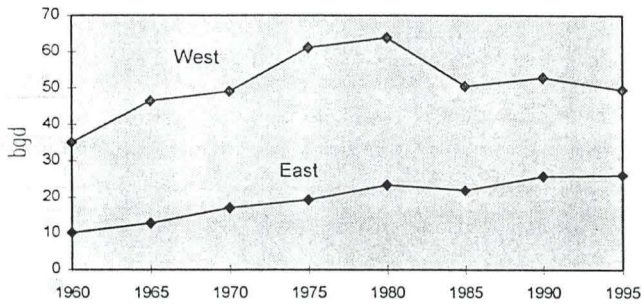

Figure 26. Ground water withdrawal

Looking at ground water pumping at the aggregated region level shows that the recent increase in pumping in the East is almost totally attributable to the Southeast, and that the 1985 decreases in pumping in the West are largely attributable to the Pacific Coast region (Figure 27).

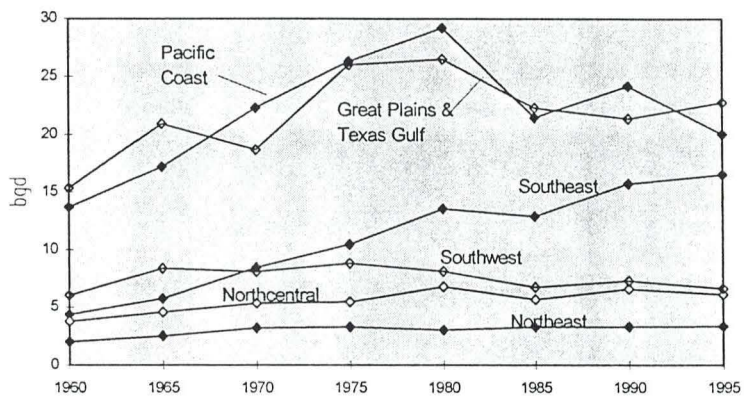

Figure 27. Ground water withdrawal by aggregated region

In 1960 ground water pumping accounted for from 30 to 42 percent of total fresh water withdrawals in the Western aggregated regions, but from only 6 to 17 percent in the Eastern aggregated regions (Figure 28). However, the portion of withdrawals coming from ground water has been dropping in the Western aggregated regions and rising in the Eastern regions. This is most evident in the Southeast aggregated region, where ground water withdrawals now make up 27 percent of total fresh water withdrawals, compared with only 24 percent for the Southwest (Figure 28). (Note that much of the rise in pumping in the Southeast aggregated region is occurring in the Lower Mississippi region (WRR 8).) Although the projected future withdrawals presented above were not allocated to surface and ground water sources in this report, it is clear that continued reliance on ground water pumping will be critical if the projected withdrawal amounts do actually occur, and that increasing pumping depths will increase the cost of pumping, causing additional pressure on surface water supplies.

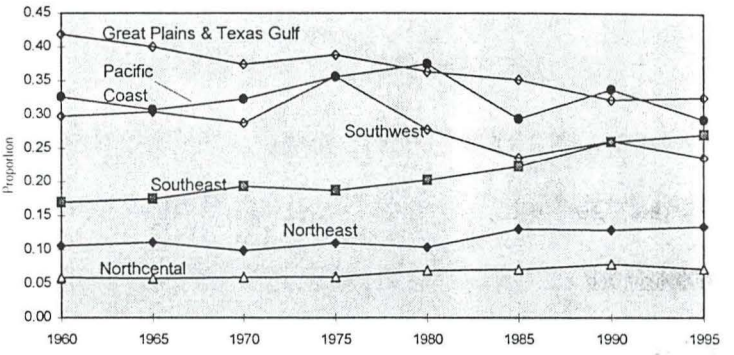

Figure 28. Portion of fresh water withdrawals taken from ground water

Summary and Conclusions

This report projects U.S. water withdrawals to year 2040 based on forecasts of population and income and on extending past trends in several key factors affecting water

use. In nearly all cases, future rates of change in factors affecting water use are projected to diminish over time, in keeping with recent nonlinear trends. This is the case whether those rates are positive, and thus tending to increase withdrawal, such as per-capita electricity use, or negative and thus tending to decrease withdrawal, such as industrial & commercial withdrawal per dollar or withdrawal per kWh. The overall approach has been to avoid complicated models, which tend to rely on arrays of obscured assumptions, and use instead a relatively straightforward extension of past trends that maintains the visual continuity of the trend, as long as those trends are sensible in light of available evidence.

Based on the best available estimates of future population, total U.S. withdrawals in year 2040 are projected to be 10 percent above those in 1995, in spite of a 41 percent increase in population (Figure 18.1). This picture is in contrast to most past projections, which have suggested dramatic increases in withdrawal (see, for example, Shabman, 1990). However, the very tenuous nature of such projections, whether they are alarming or comforting, should not be forgotten. Predicting the future is impossible, and projections are most useful when used to highlight the kinds of changes in public policy that may help avoid troublesome or costly future inefficiencies.

All the factors affecting water use that are analyzed in this report (e.g., population, withdrawal per household, kWh per person, irrigated acres), plus some other factors affecting water use that were not analyzed (e.g., changes in hydropower capacity), are subject to public policy. For example, population is subject to immigration policy; withdrawal per household and kWh per person are subject to water or electricity prices as well as regulations affecting the efficiency of water- or power-using appliances; and irrigated acreage is subject to a host of influences including subsidization of water supply,

crop price supports, international trade policy, and regulations affecting the ease with which water trades may occur. Policy changes alter water use in ways not captured by the method of extending past trends in water use efficiencies as done herein. Indeed, the purpose of this report is to highlight areas where policy changes should be considered. So, what such changes do these projections suggest? Four obvious ones will be offered.

First, improvements in the efficiency of water use have had a very positive effect on withdrawals, decreasing use considerably below what was projected by earlier studies that ignored the effects of changing efficiencies. Further improvements in water use efficiency must be encouraged, or at least not discouraged. Further improvements are likely to follow the kind of influences that encouraged past improvements, such as plumbing fixture ordinances, price increases, reductions in government subsidies, and environmental pollution regulations. The cautiously optimistic projections presented herein rely critically on continued improvements in efficiencies in industry, thermoelectricity, and irrigation.

Second, we must strive to remove remaining barriers to voluntary water trades, allowing the market to reallocate water to its most valuable uses. This will be particularly important in the West, where water is relatively scarce. For example, in the Colorado River Basin, projected increases in the Upper Basin will, if they occur, probably force decreases in withdrawals downstream, especially in Southern California. It is useful to remember that much of the projected increase in withdrawal in the Upper Basin would result from increased irrigation, and that much of the irrigation in that region is used to grow relatively low-valued feed grains and forage crops. It would seem that opportunities to trade are ample.

Third, given the large increase in withdrawal projected for areas of the South (especially WRRs 3 and 8) and given the likely prospect that much of the projected withdrawal increases will come from increased ground water pumping, states in these regions will probably be facing greater conflicts between ground water and surface water wherever ground water pumping affects surface water flow. As conflicts become more common, water law and policy will be forced to take greater recognition of the conjunctive nature of these two sources of water, and of the salt water intrusion problem in some in coastal areas of the South.

Fourth, meeting the offstream water needs of the growing population will unavoidably decrease instream flows, leading to greater environmental conflicts, not only in the West but also in some Eastern areas. Law and policy will be forced to respond to growing concerns about instream flow.

As presented in Table 7, the best-guess projections of this report can be substantially altered by changes in the basic assumptions on which the projections are based. For example, if population turns out to be 10 percent above expected, withdrawals increase by from 1 percent (WRR 14) to 11 percent (WRR 6) above the best-guess projections. Any or all of the assumptions made in this report about factors affecting projected withdrawals may turn out to have been optimistic. Further, factors ignored in this report may turn out to play a significant role in increasing demand for withdrawals. In addition, it must be remembered that this study has ignored the problems of climatic variability (e.g., droughts). And it must also be recognized that, in the event that the best guess projections are accurate or even overestimates, they apply to the average year, not to the more worrisome dry years, and to large scale regions, not to specific locations that may

experience above average impacts. The chance of such unhappy occurrences suggests that it is only prudent of U.S. water policy makers to encourage water conservation and improvements in the efficiency of water use when such changes can be accomplished without exorbitant cost. If the worst never happens, the unexpected beneficiaries of the policy changes will be the health and beauty of riparian ecosystems.

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Fig. 18.1

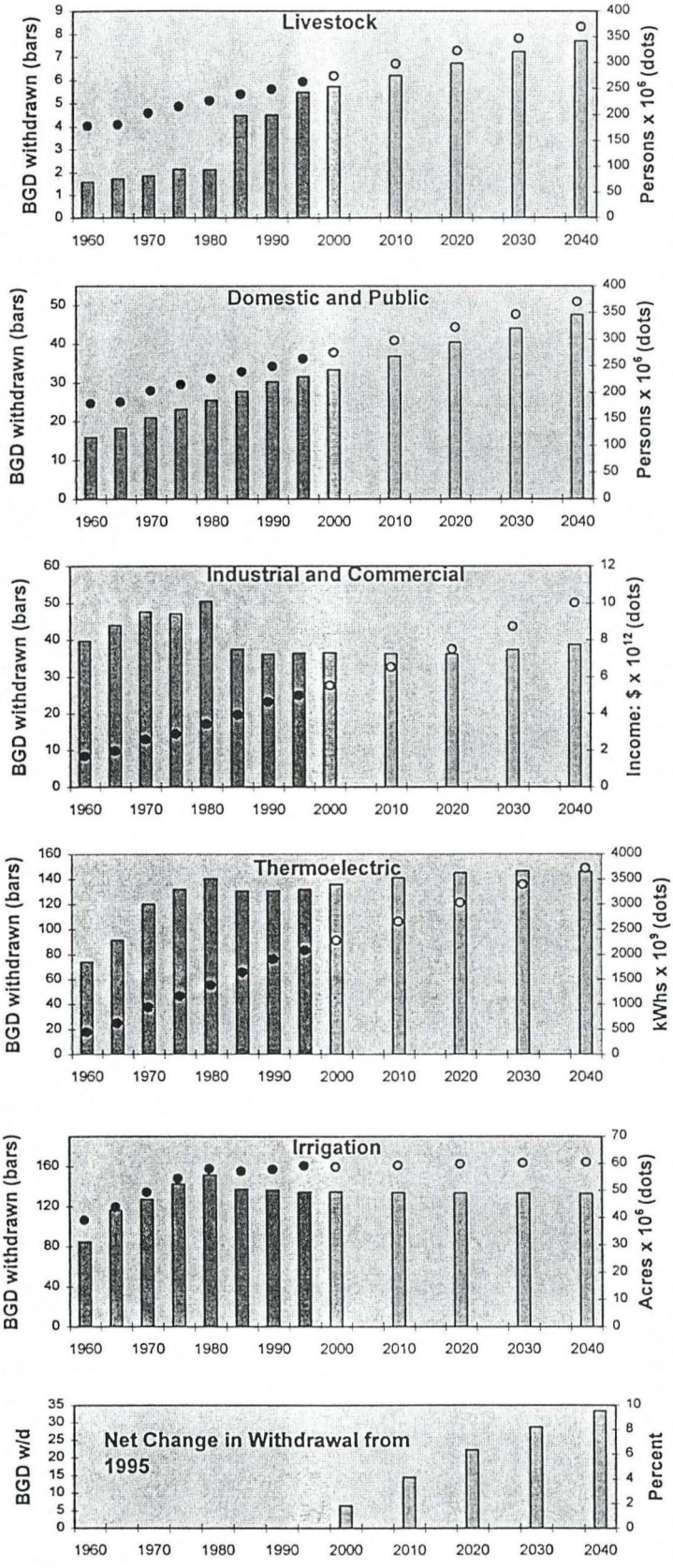

Livestock
BGD withdrawn (bars)
Persons x 10^6 (dots)
Domestic and Public
BGD withdrawn (bars)
Persons x 10^6 (dots)
Industrial and Commercial
BGD withdrawn (bars)
Income: $ x 10^12 (dots)
Thermoelectric
BGD withdrawn (bars)
kWhs x 10^9 (dots)
Irrigation
BGD withdrawn (bars)
Acres x 10^6 (dots)
Net Change in Withdrawal from 1995
BGD w/d
Percent
1960 1970 1980 1990 2000 2010 2020 2030 2040

Fig. 18.2

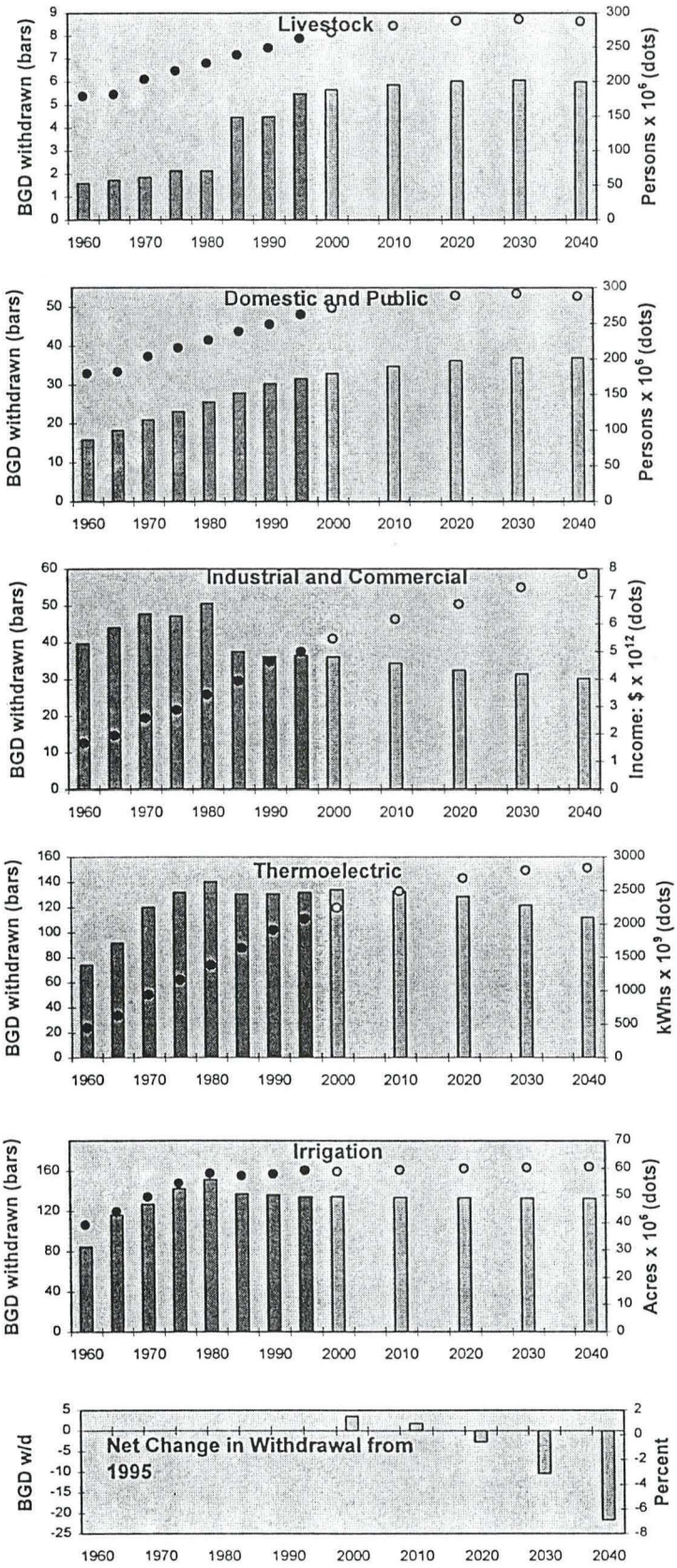
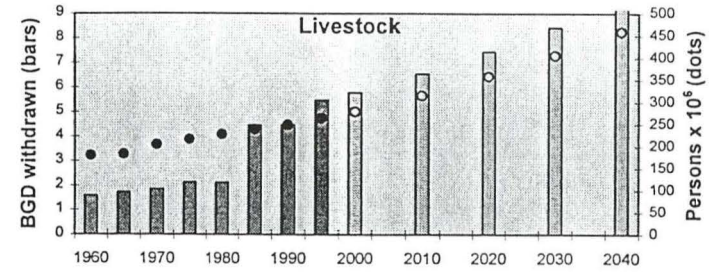

Livestock
BGD withdrawn (bars)
Persons x 10^6 (dots)
Domestic and Public
BGD withdrawn (bars)
Persons x 10^6 (dots)
Industrial and Commercial
BGD withdrawn (bars)
Income: $ x 10^12 (dots)
Thermoelectric
BGD withdrawn (bars)
kWhs x 10^9 (dots)
Irrigation
BGD withdrawn (bars)
Acres x 10^6 (dots)
Net Change in Withdrawal from 1995
BGD w/d
Percent
1960 1970 1980 1990 2000 2010 2020 2030 2040

Fig. 18.3


Livestock
BGD withdrawn (bars)
Persons x 10^6 (dots)
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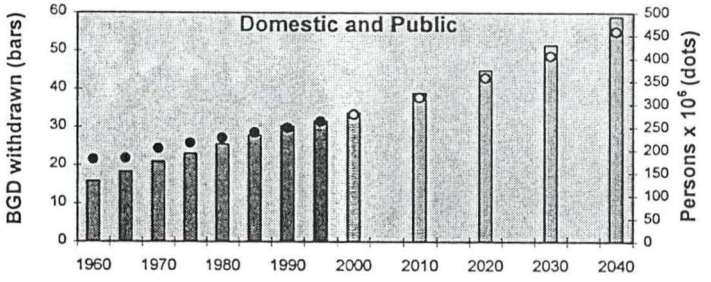
0 50 100 150 200 250 300 350 400 450 500
1960 1970 1980 1990 2000 2010 2020 2030 2040


Domestic and Public
BGD withdrawn (bars)
Persons x 10^6 (dots)
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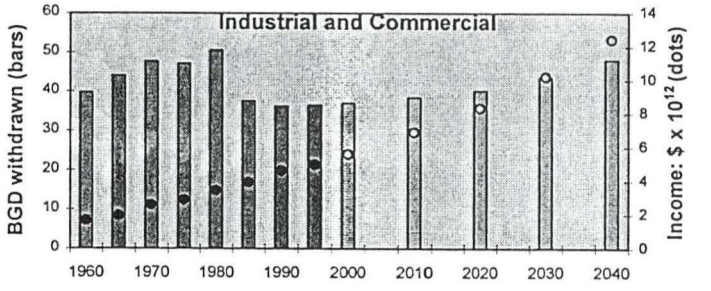
0 50 100 150 200 250 300 350 400 450 500
1960 1970 1980 1990 2000 2010 2020 2030 2040


Industrial and Commercial
BGD withdrawn (bars)
Income: $ x 10^12 (dots)
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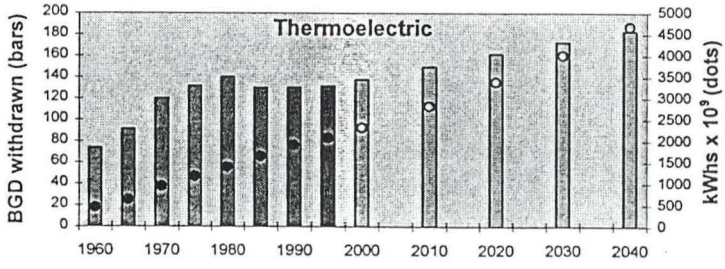
0 2 4 6 8 10 12 14
1960 1970 1980 1990 2000 2010 2020 2030 2040


Thermoelectric
BGD withdrawn (bars)
kWhs x 10^9 (dots)
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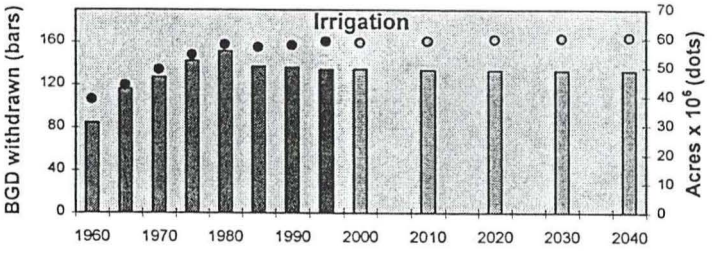
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
1960 1970 1980 1990 2000 2010 2020 2030 2040


Irrigation
BGD withdrawn (bars)
Acres x 10^6 (dots)
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0 10 20 30 40 50 60 70
1960 1970 1980 1990 2000 2010 2020 2030 2040

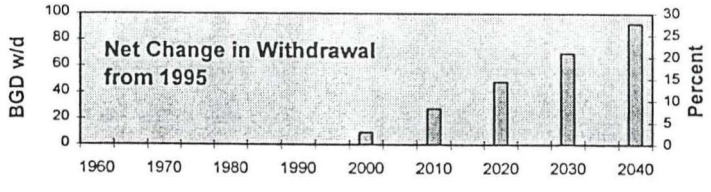

Net Change in Withdrawal
from 1995
BGD w/d
Percent
0 20 40 60 80 100
0 5 10 15 20 25 30
1960 1970 1980 1990 2000 2010 2020 2030 2040

Fig. 24.1

Northeast (WRRs 1 & 2)

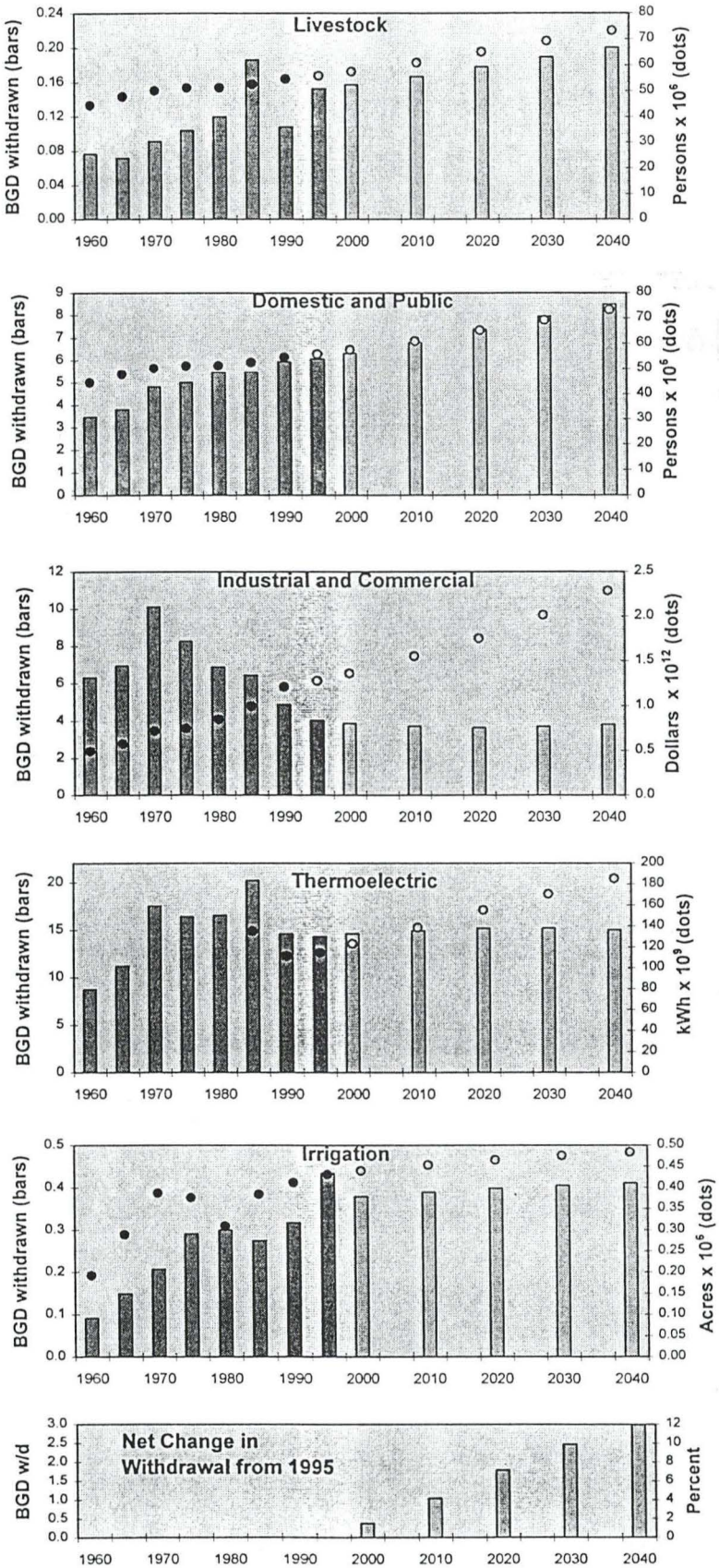
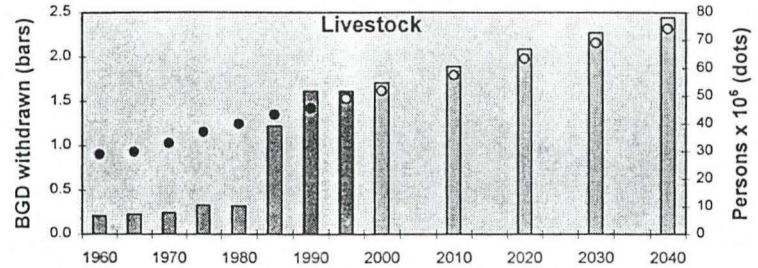
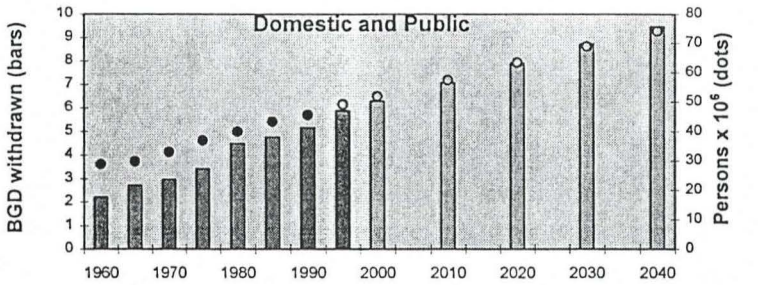
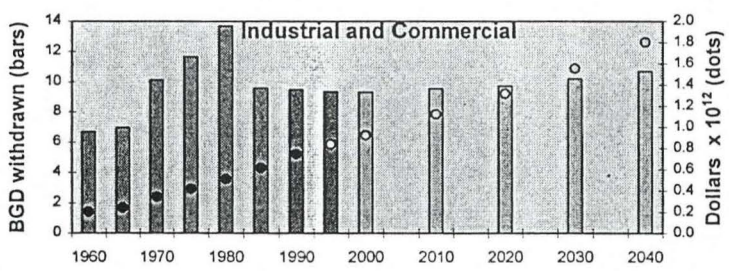


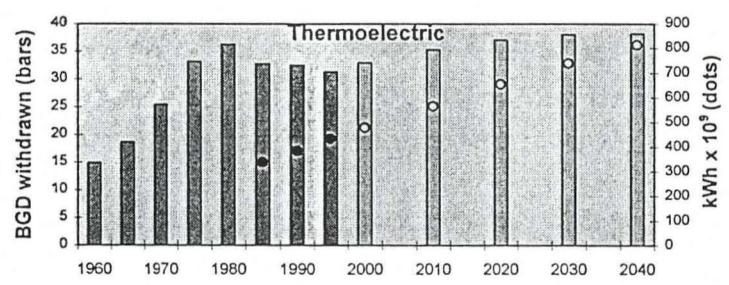
Fig. 24.2

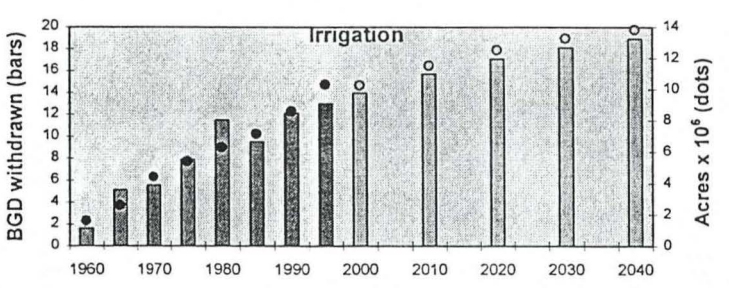
Southeast (WRRs 3, 6 & 8)











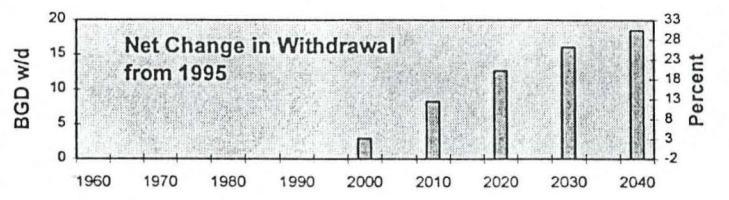


Fig. 24.3

Northcentral (WRRs 4, 5, 7 & 9)

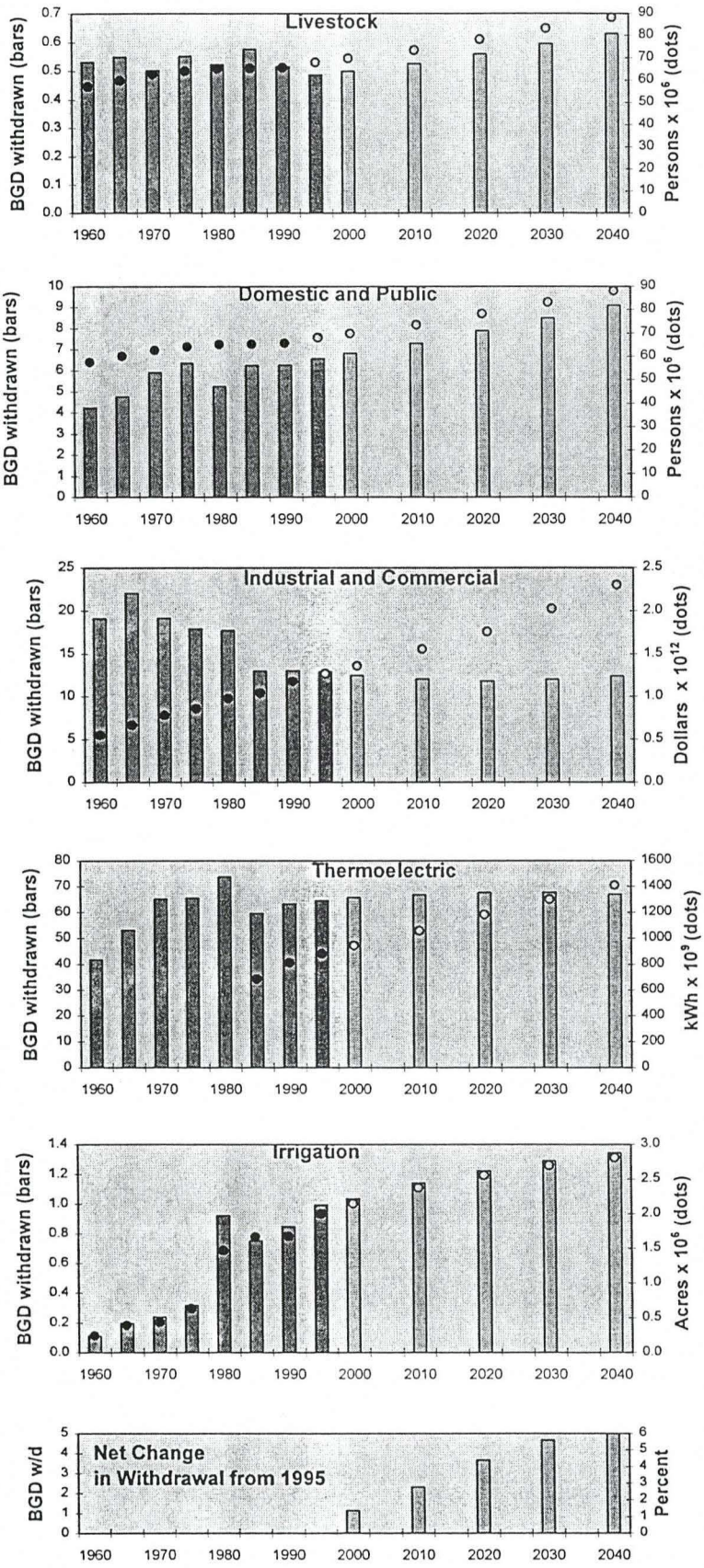


Fig. 24.4

Great Plains and Texas Gulf (WRRs 10, 11 & 12)

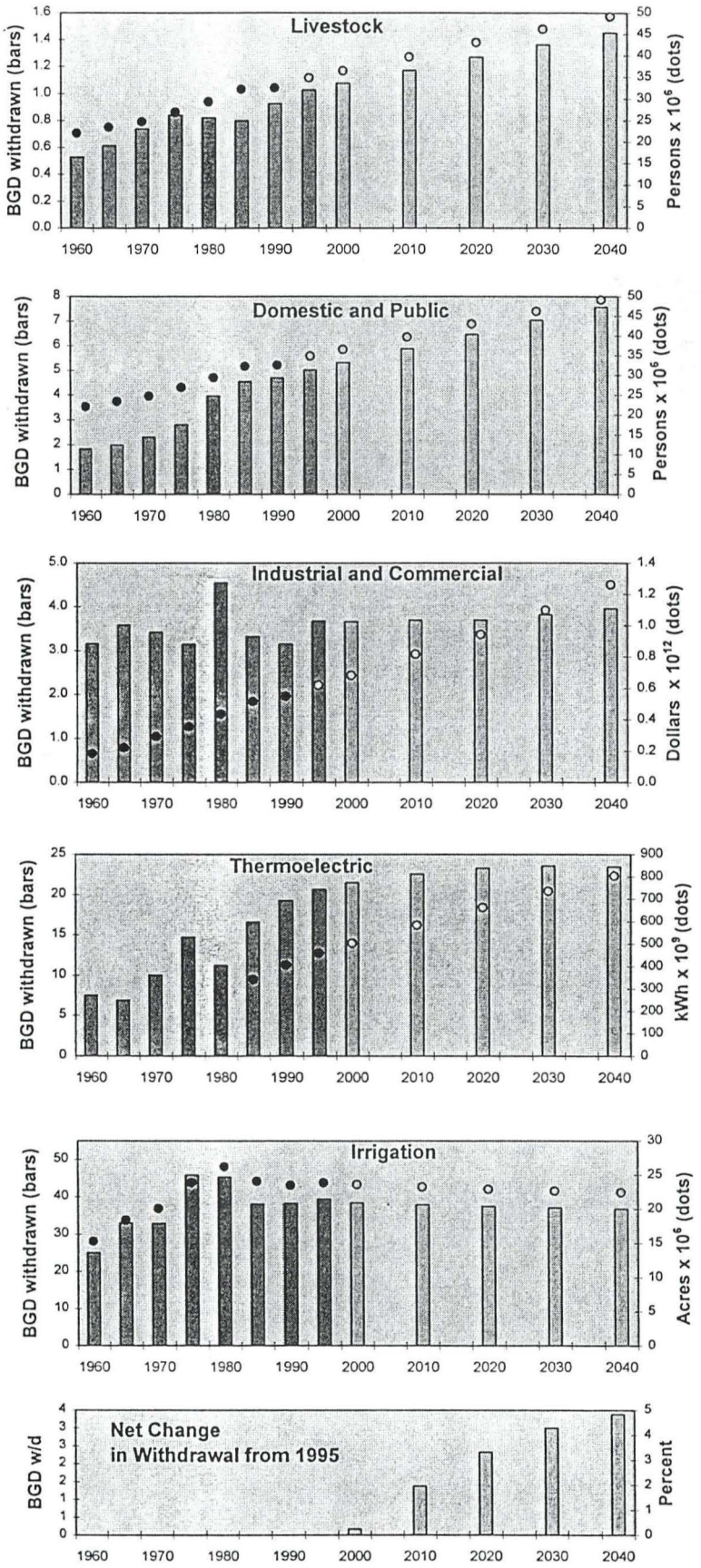
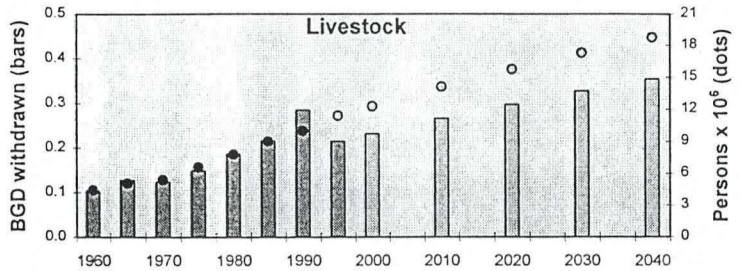
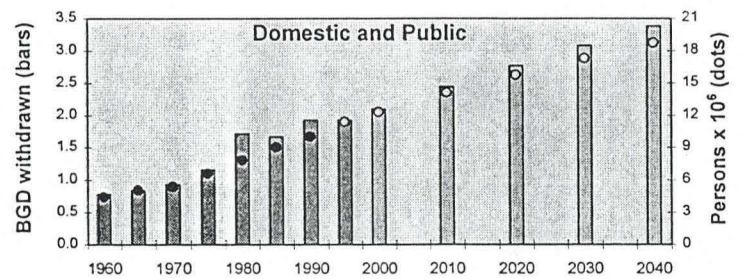
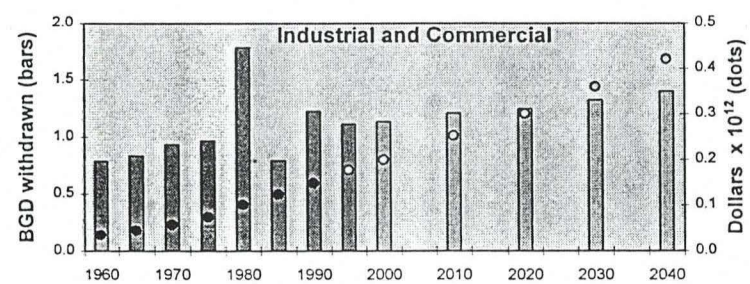


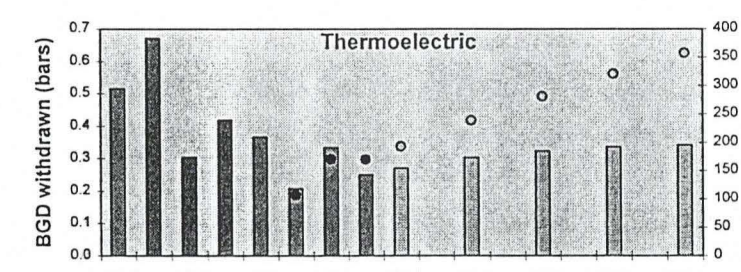
Fig. 24.5

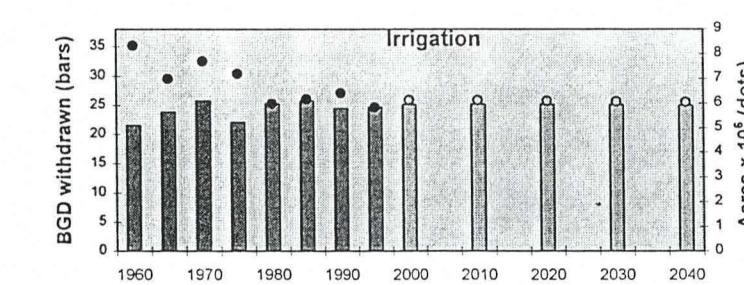
Southwest (WRRs 13, 14, 15 & 16)











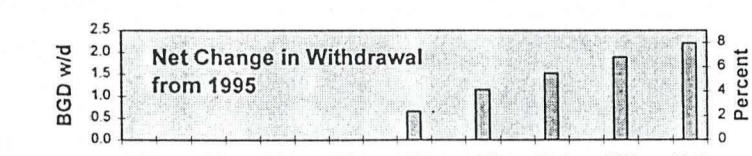
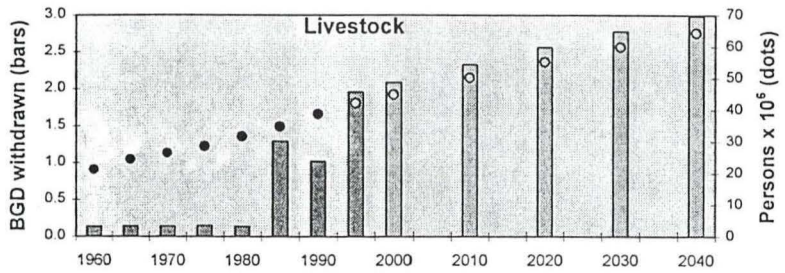
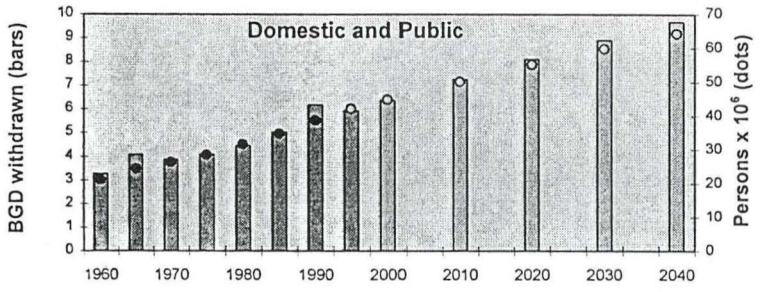
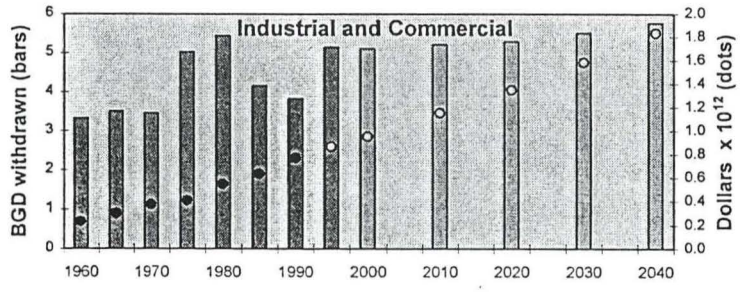


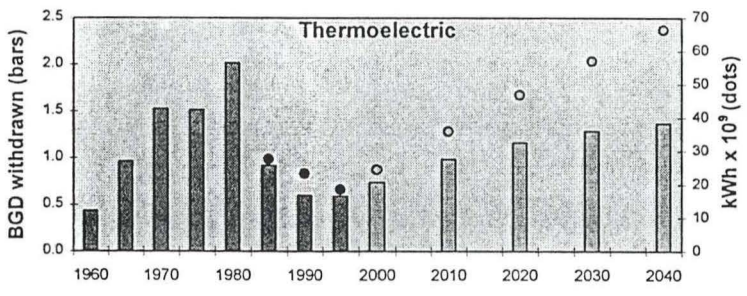
Fig. 24.6

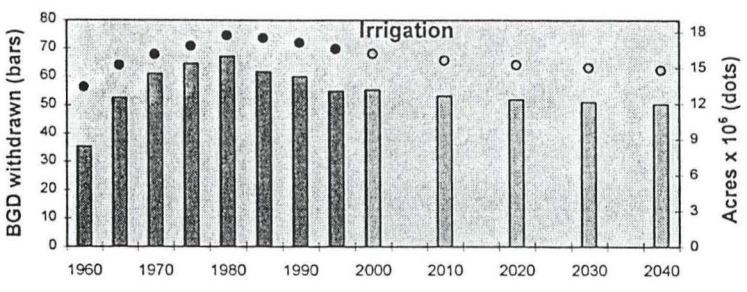
Pacific Coast (WRRs 17 & 18)











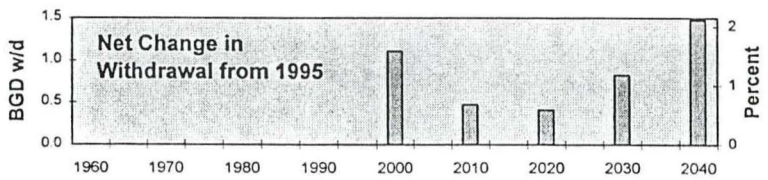


Fig. 25.1

New England (WRR 1)

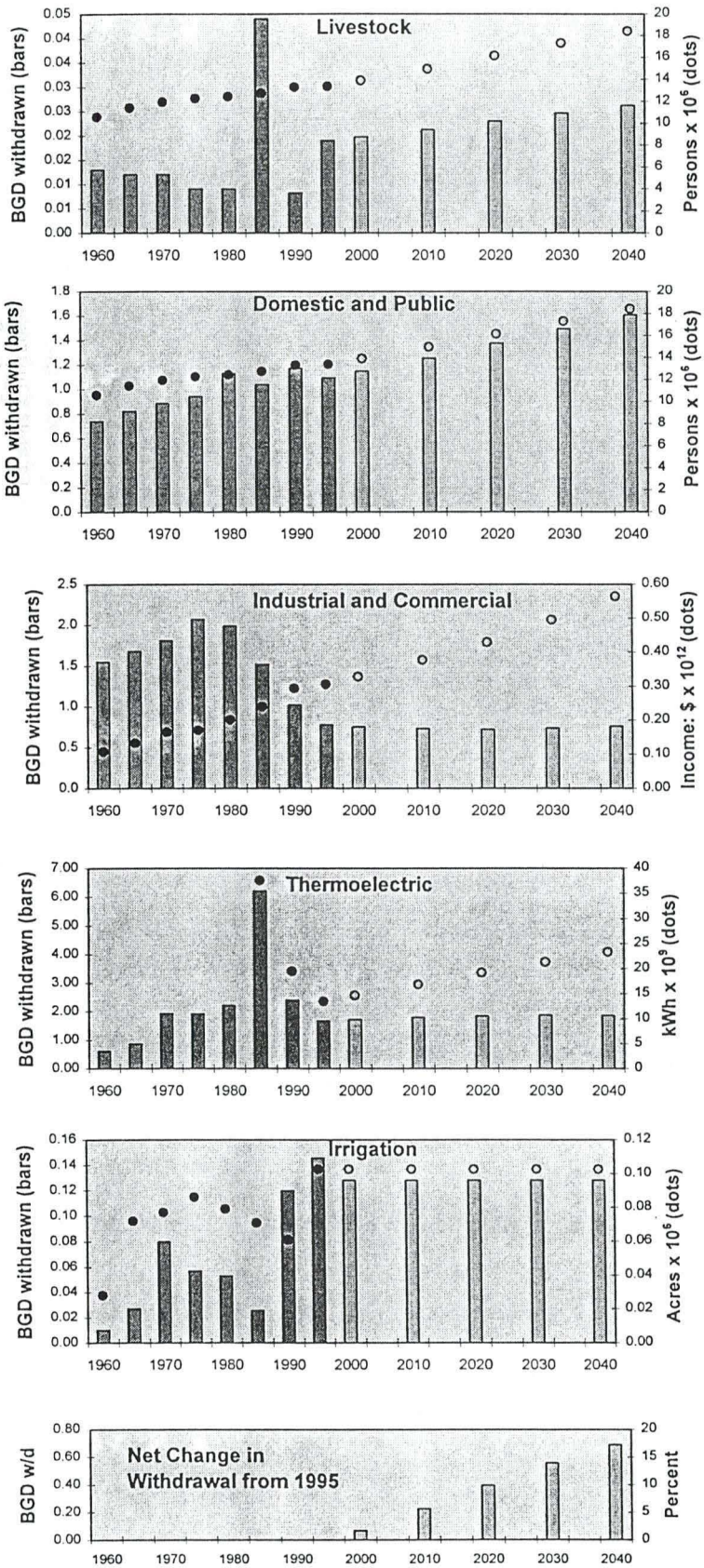


Fig. 25.2

Mid-Atlantic (WRR 2)

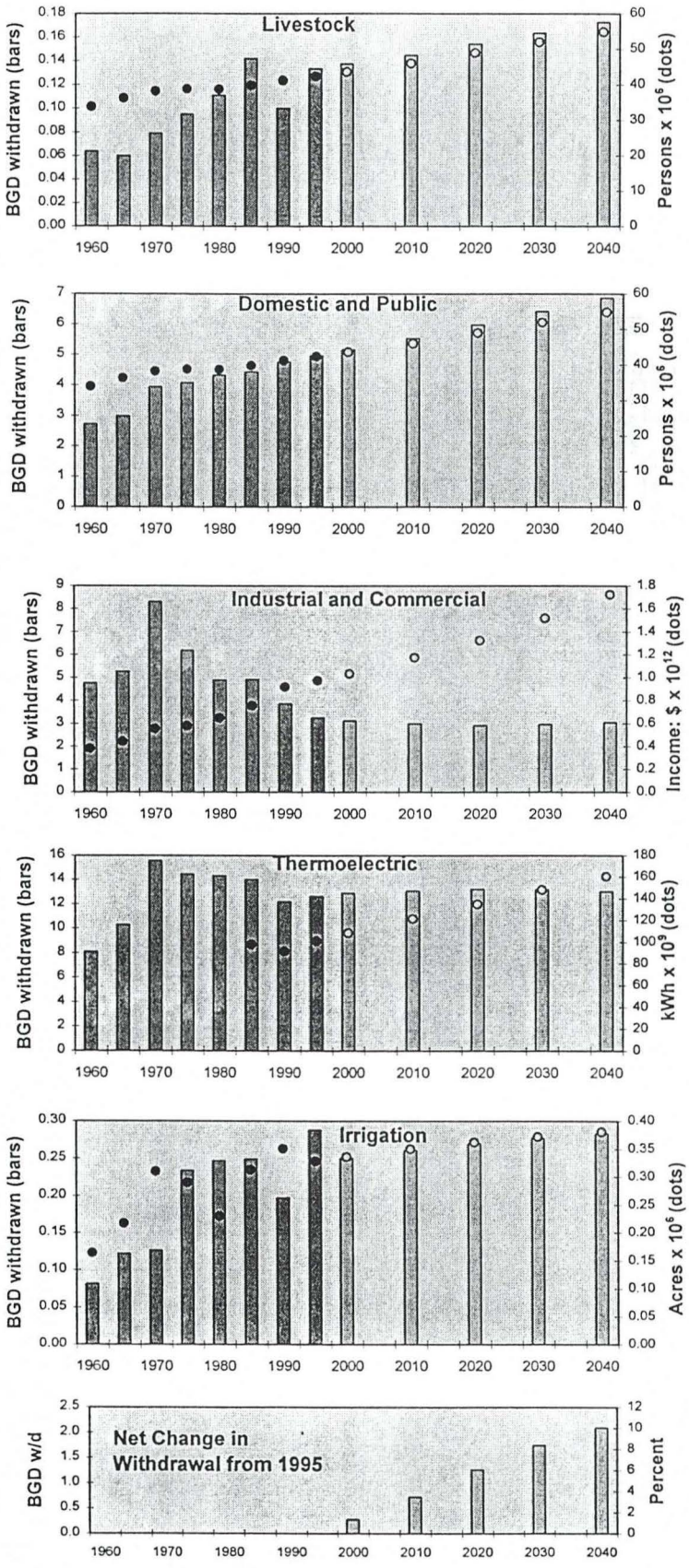
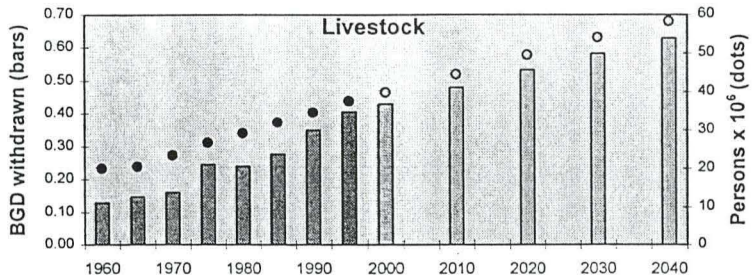
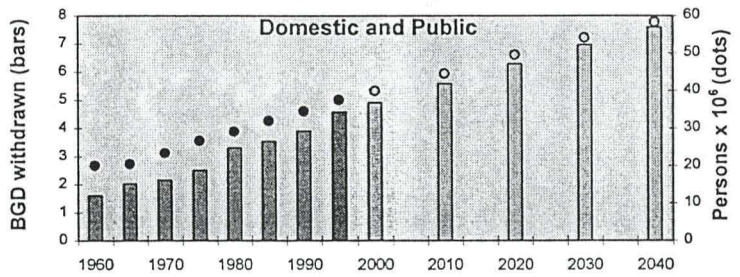
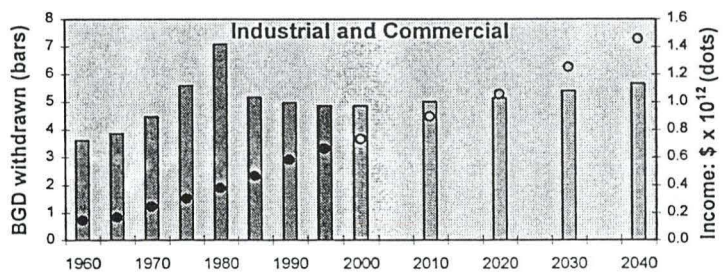


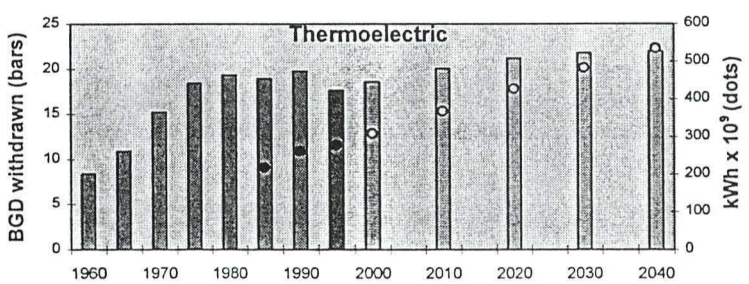
Fig. 25.3

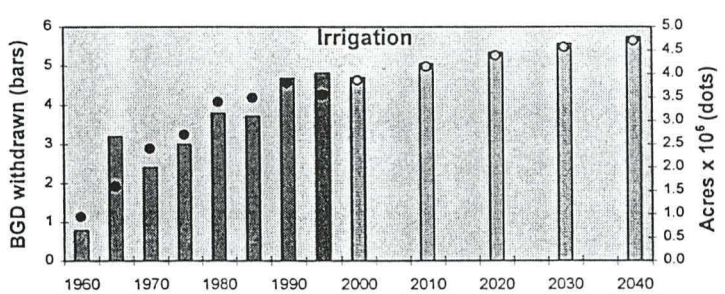
South Atlantic-Gulf (WRR 3)











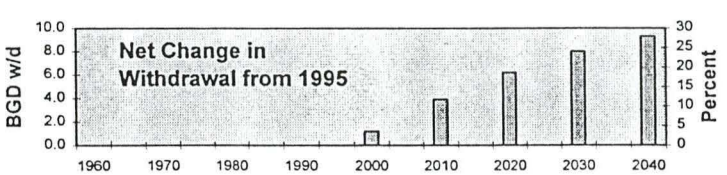


Fig. 25.4

Great Lakes (WRR 4)

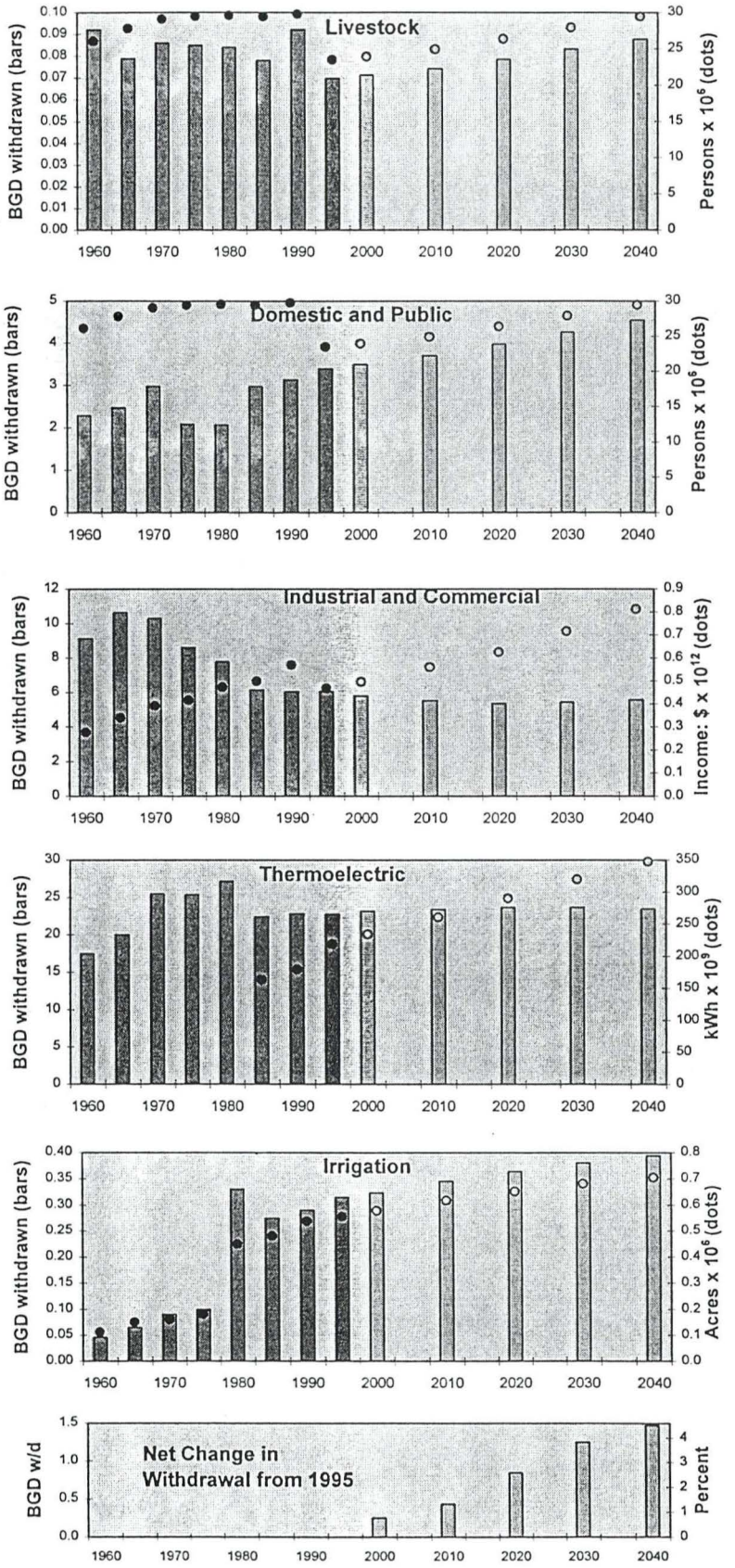
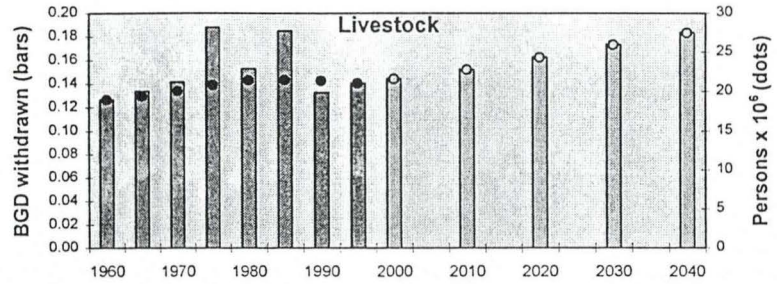
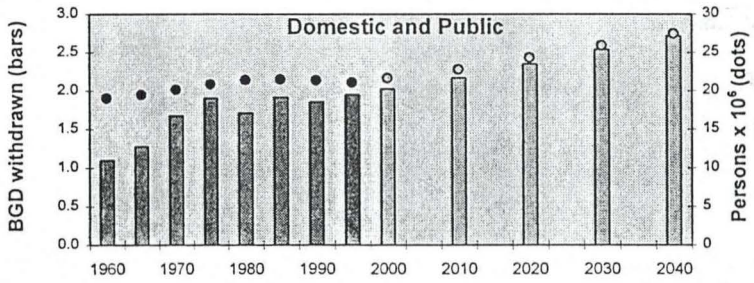
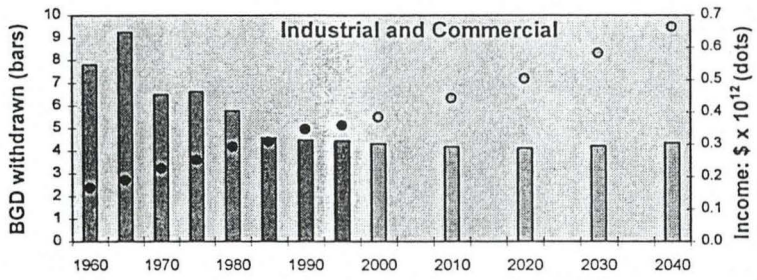


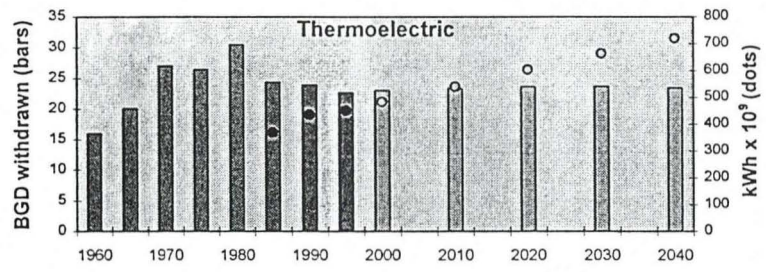
Fig. 25.5

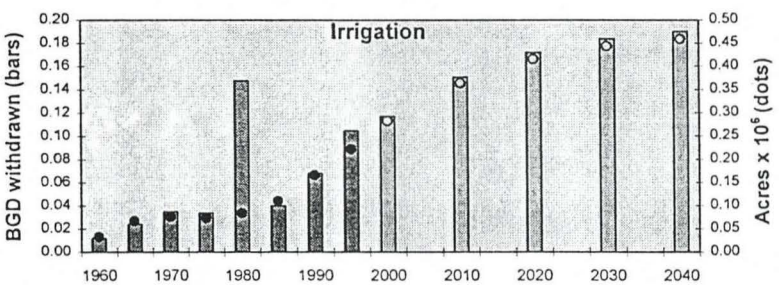
Ohio (WRR 5)











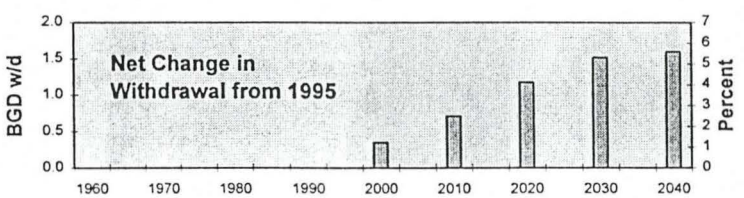
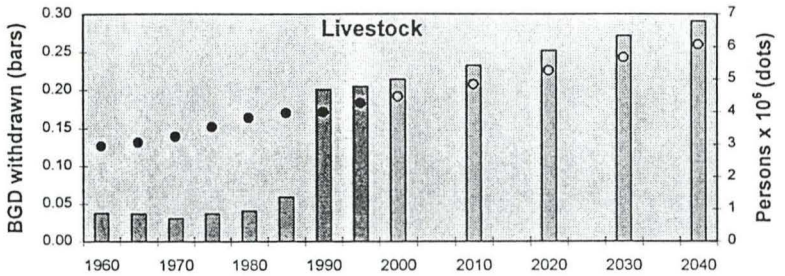
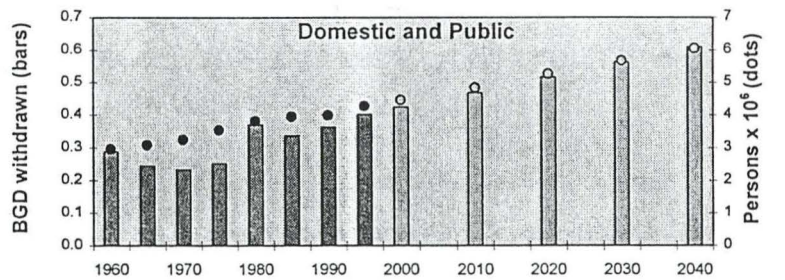
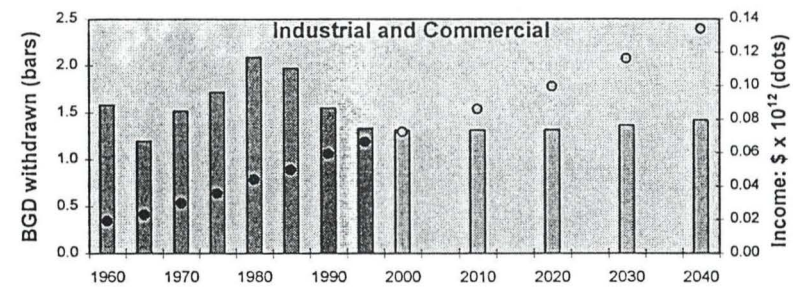


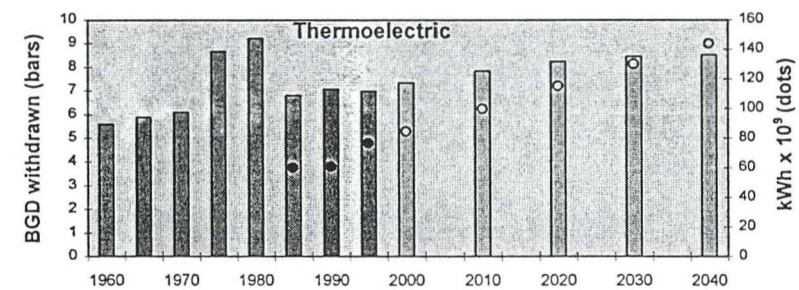
Fig. 25.6

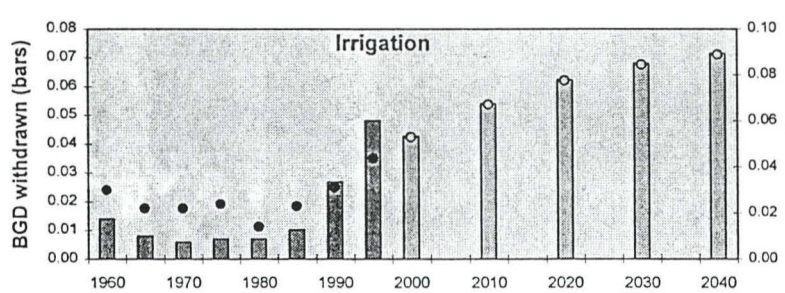
Tennessee (WRR 6)











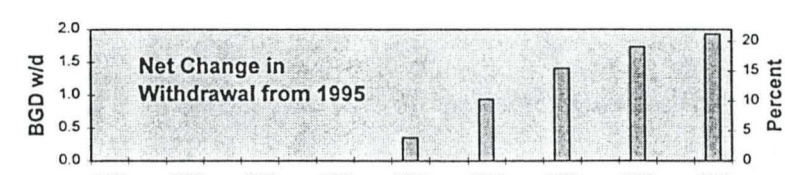
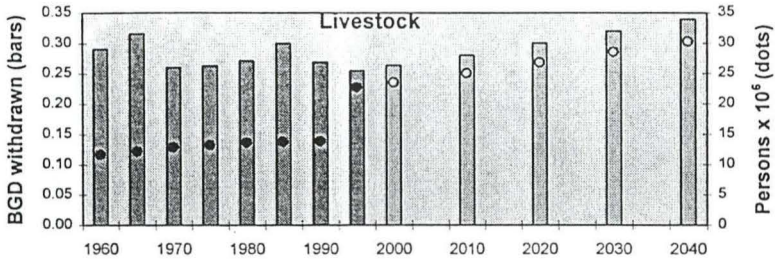
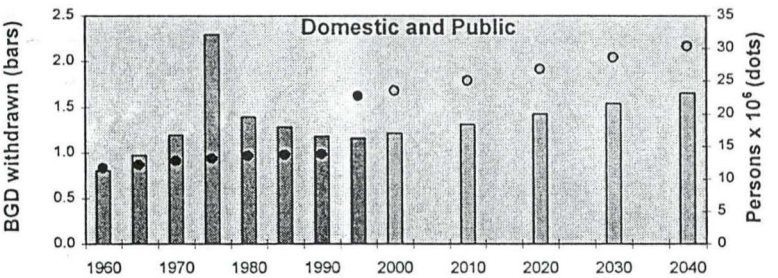
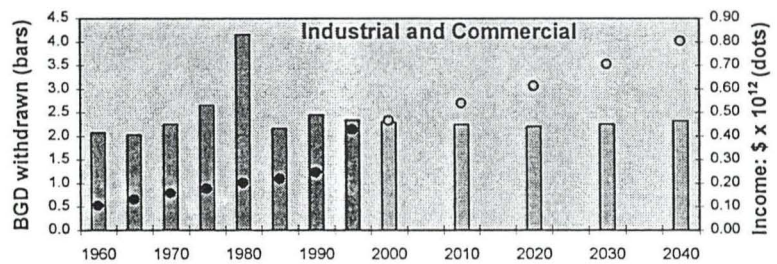


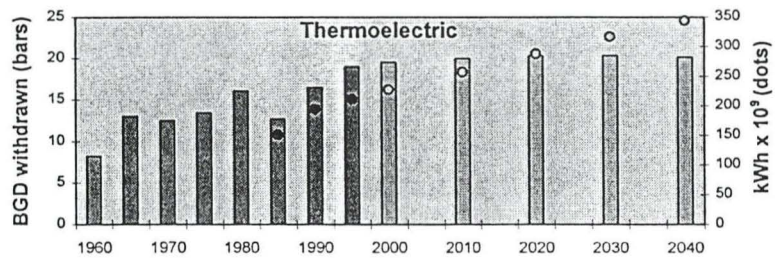
Fig. 25.7

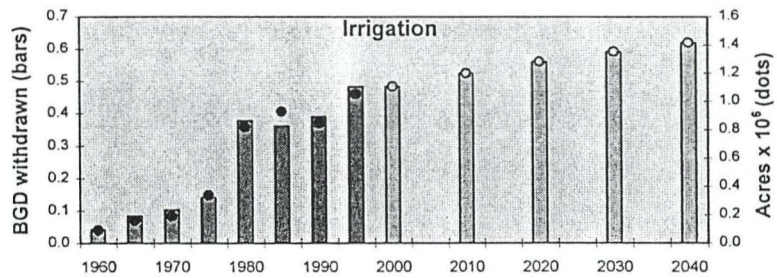
Upper Mississippi (WRR 7)











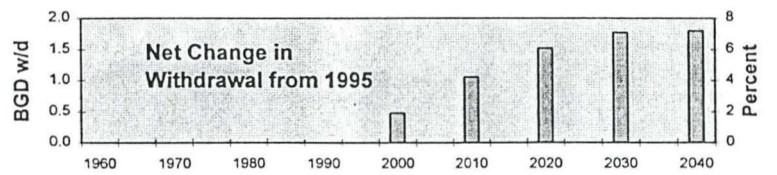
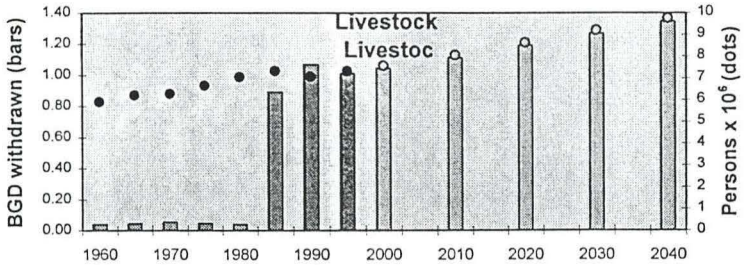
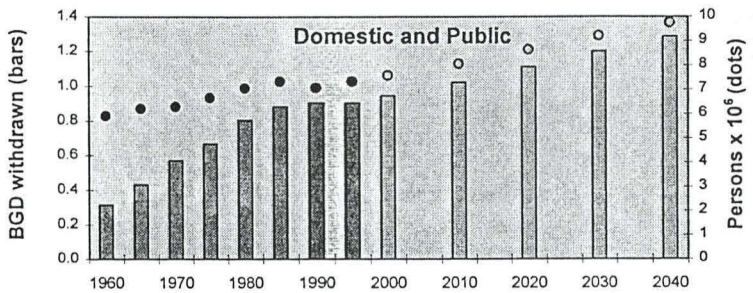
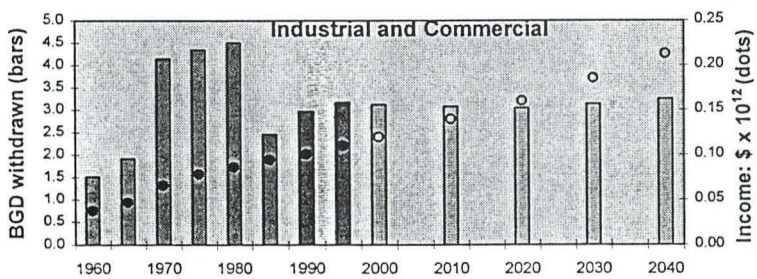


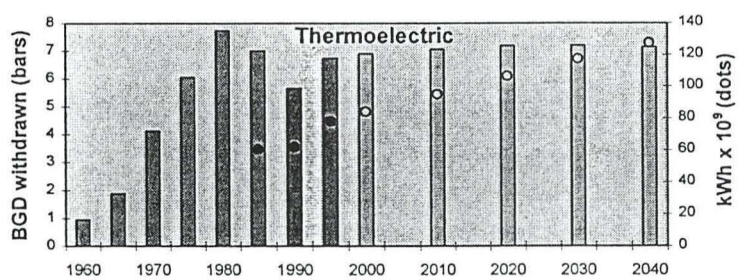
Fig. 25.8

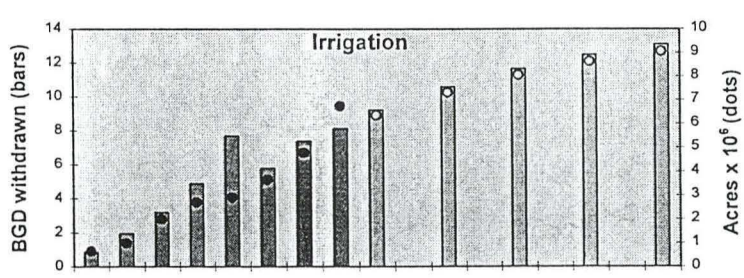
Lower Mississippi (WRR 8)











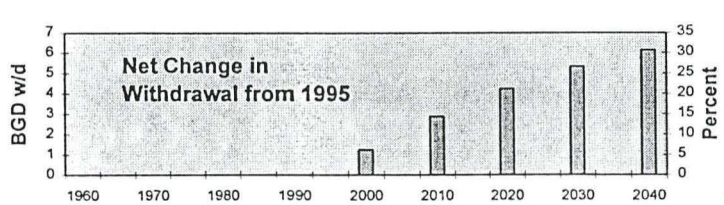
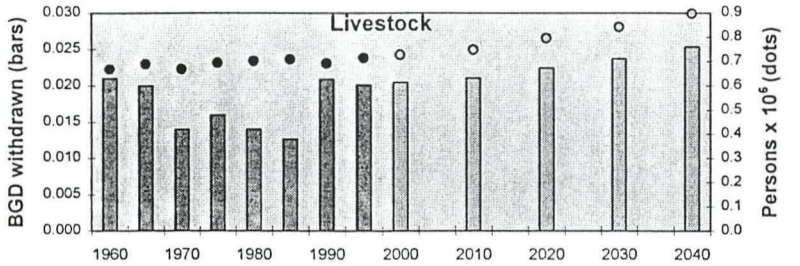
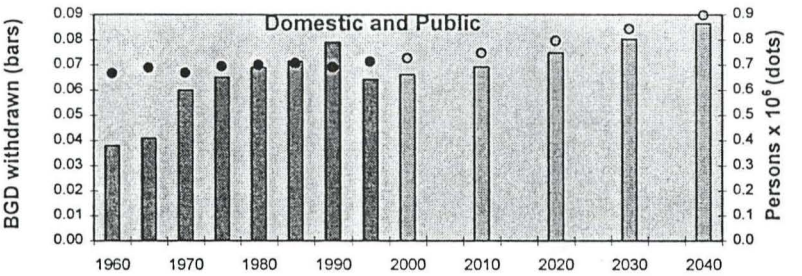
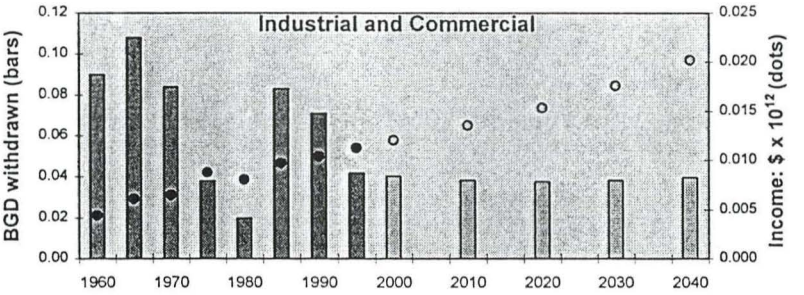


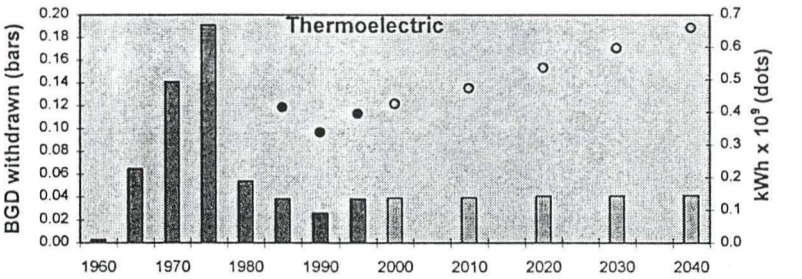
Fig. 25.9

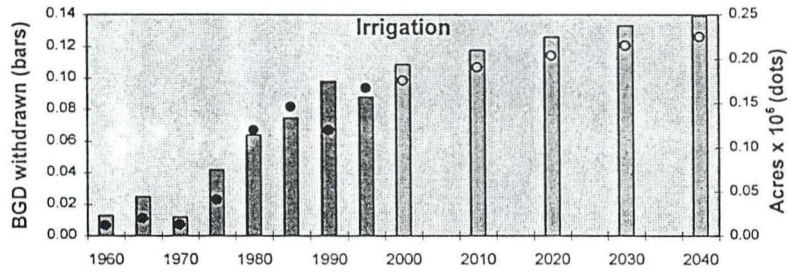
Souris-Red-Rainy (WRR 9)











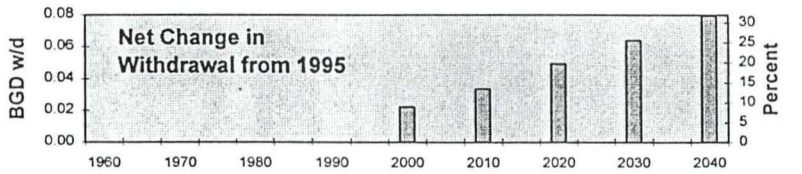


Fig. 25.10

Missouri (WRR 10)

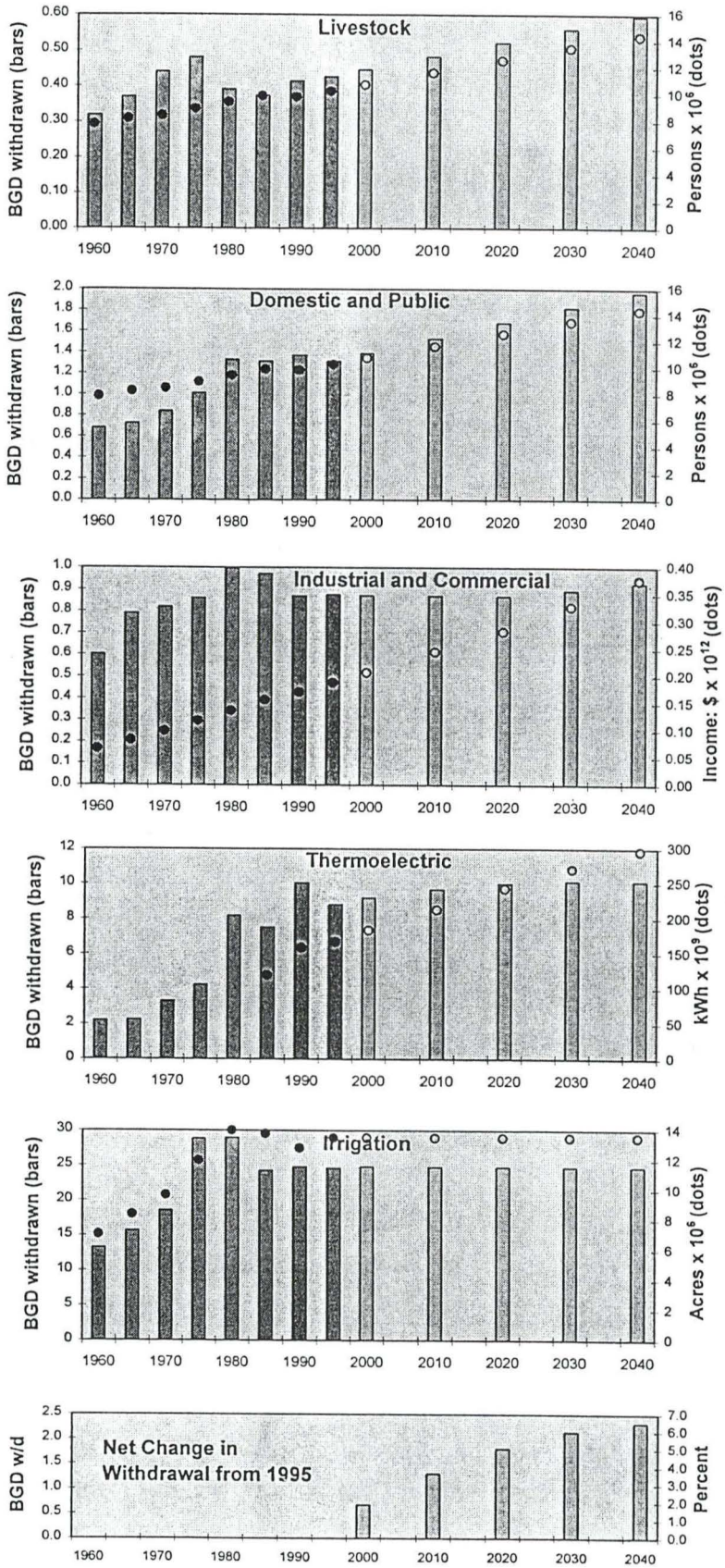
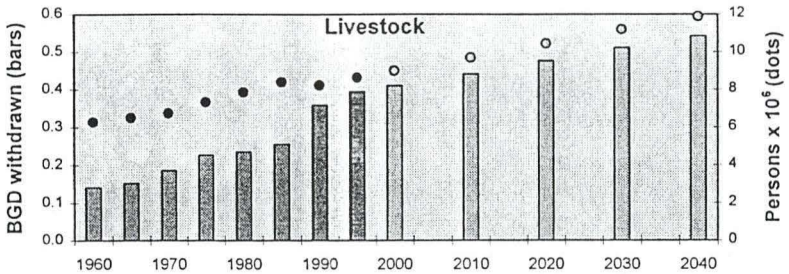
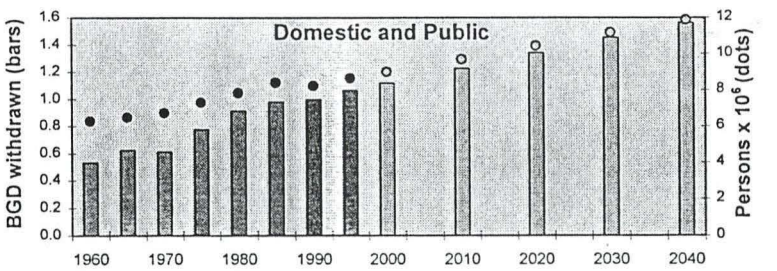
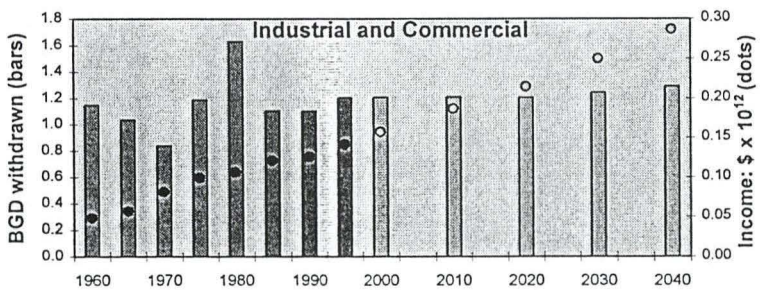


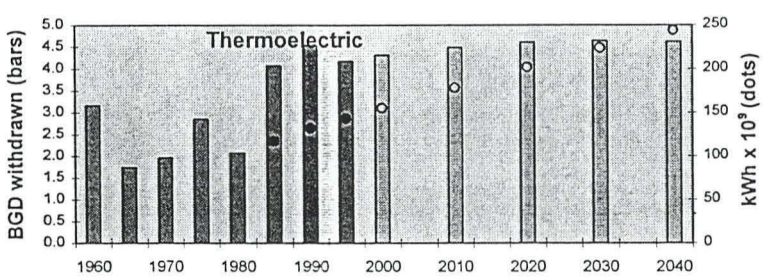
Fig. 25.11

Arkansas-White-Red (WRR 11)









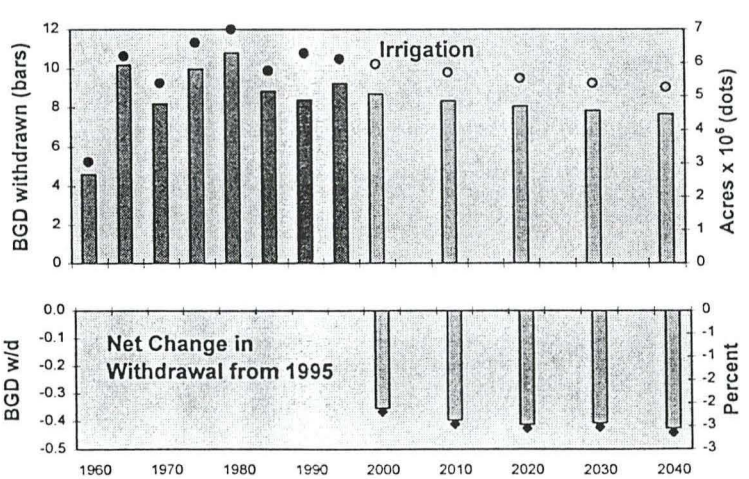


Fig. 25.12

Texas Gulf (WRR 12)

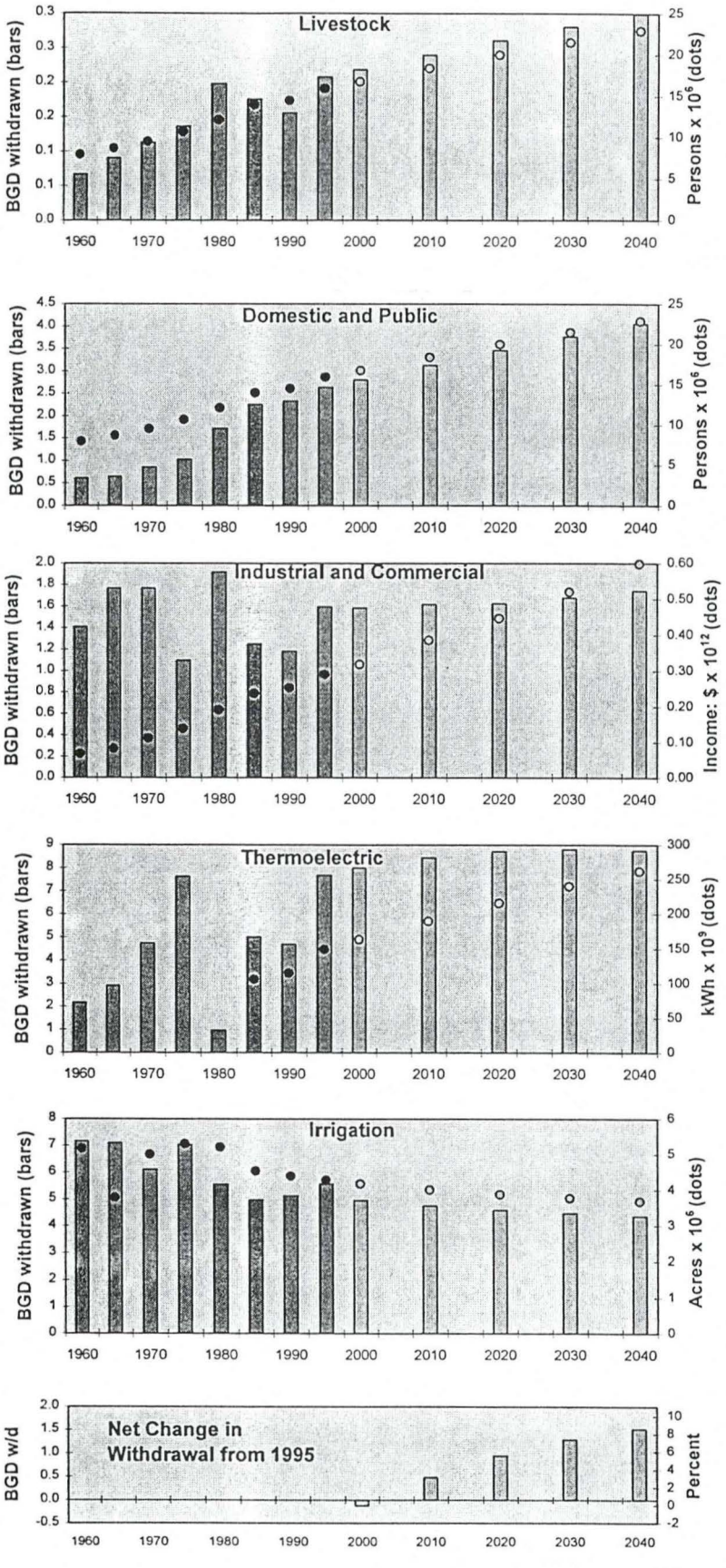


Fig. 25. 13

Rio Grande (WRR 13)

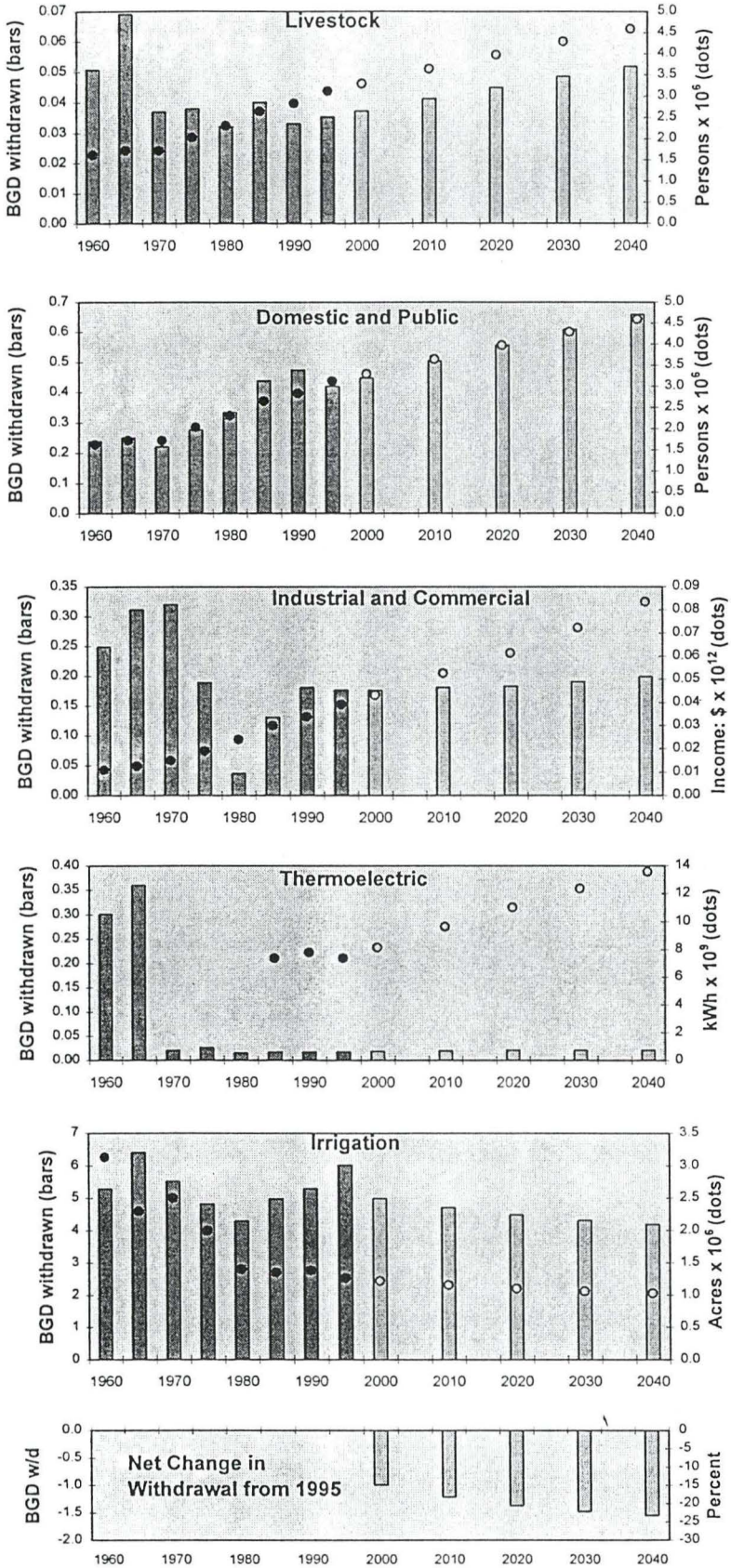
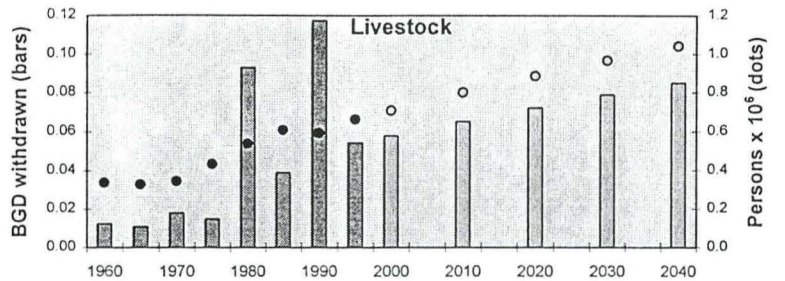
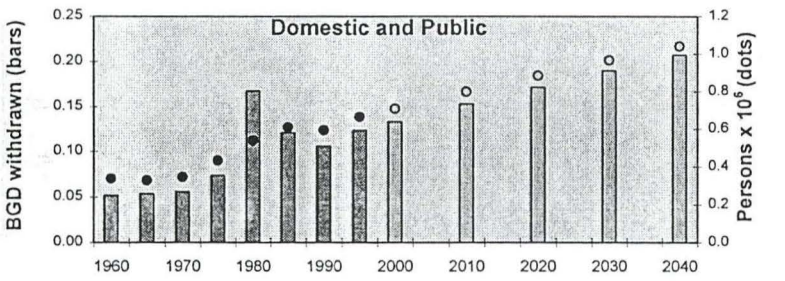
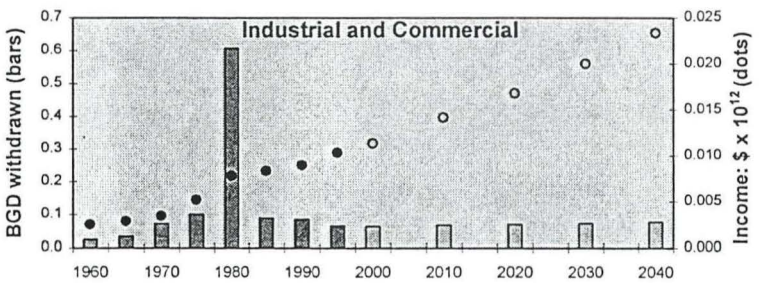


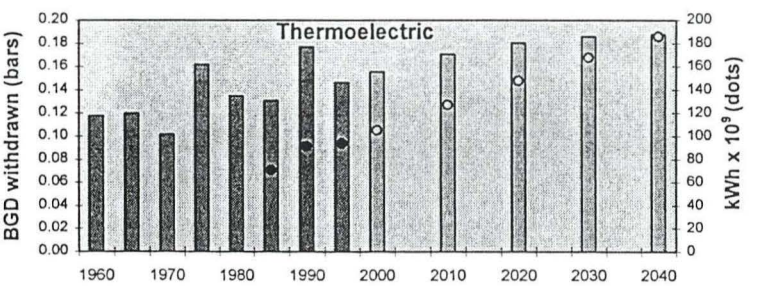
Fig. 25.14

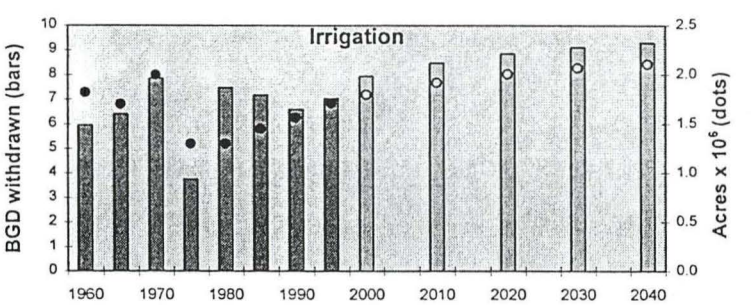
Upper Colorado (WRR 14)











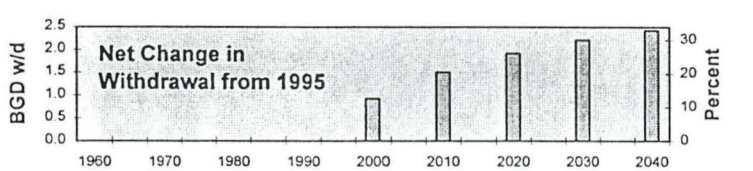
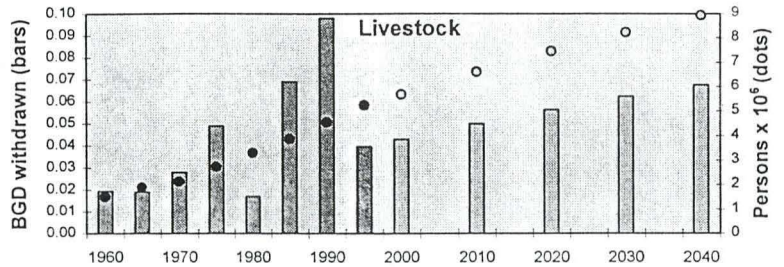
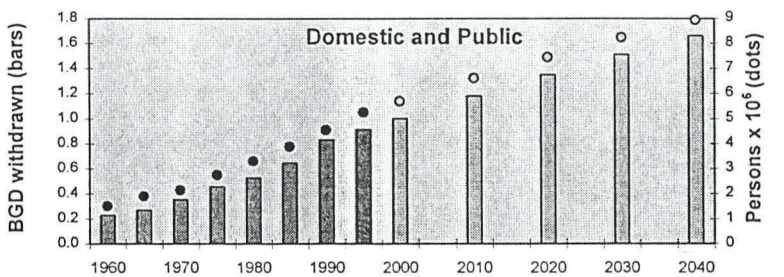
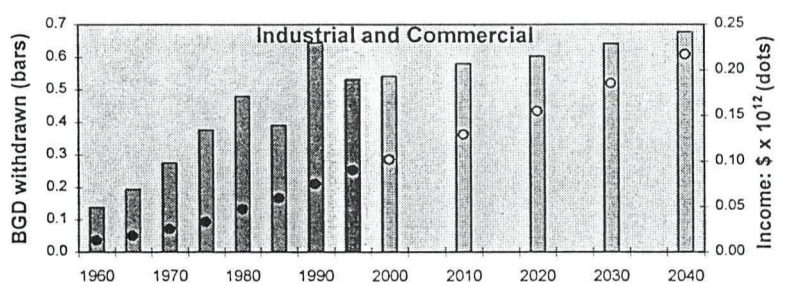


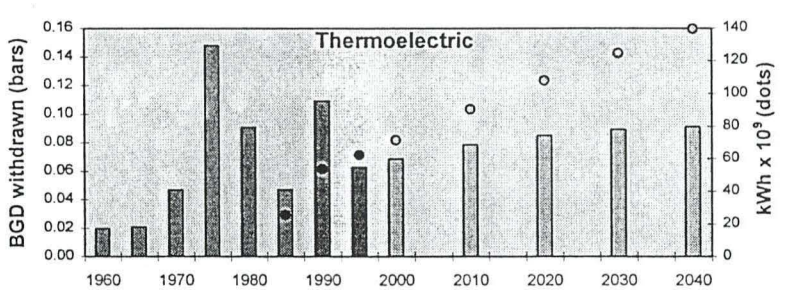
Fig. 25.15

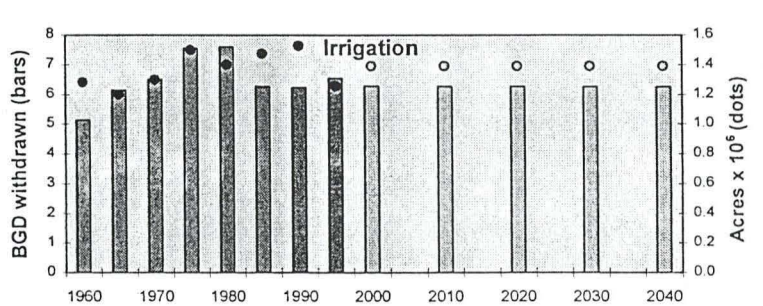
Lower Colorado (WRR 15)











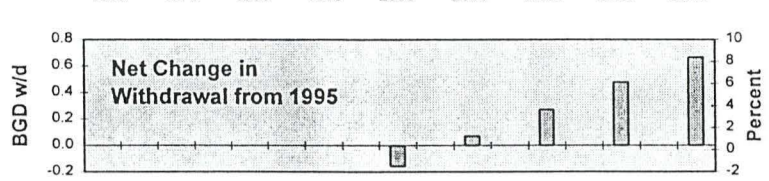


Fig. 25.16

Great Basin (WRR 16)

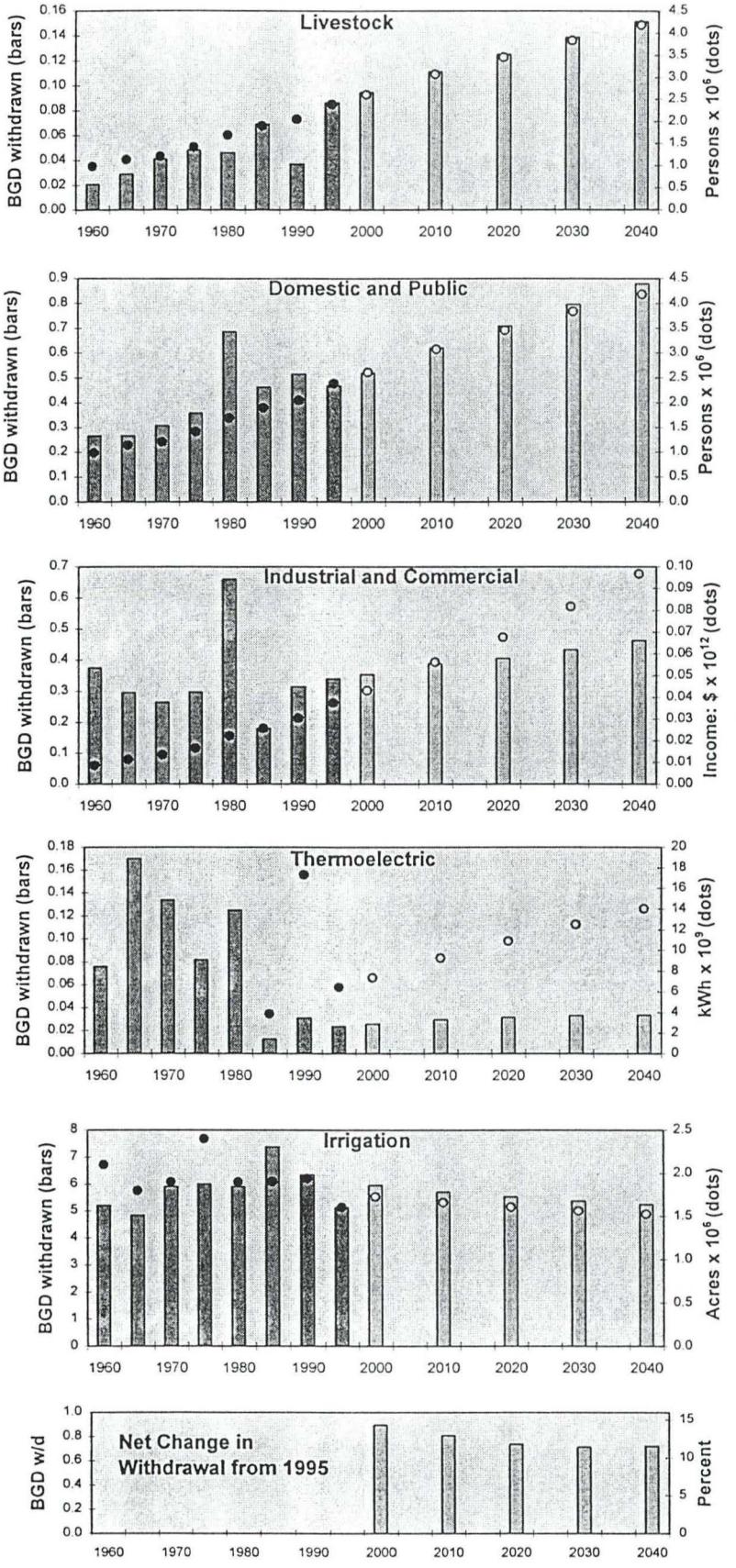
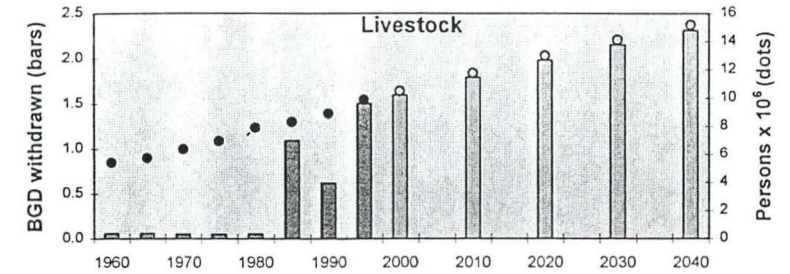
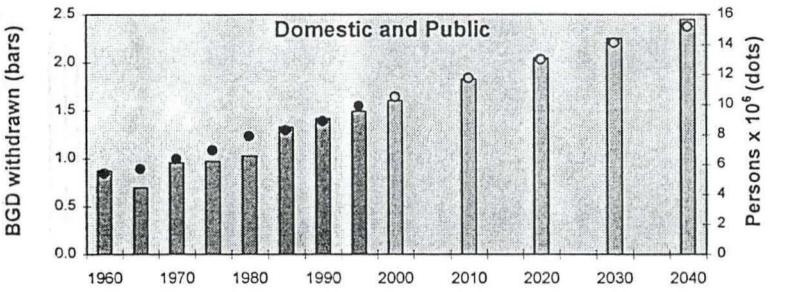
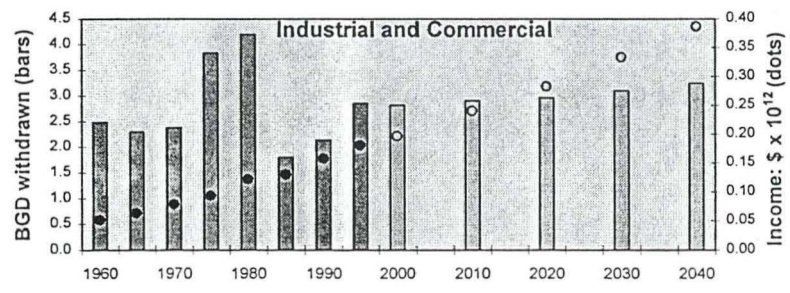


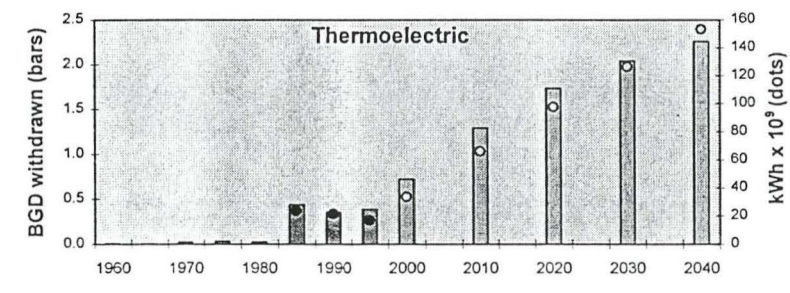
Fig. 25.17

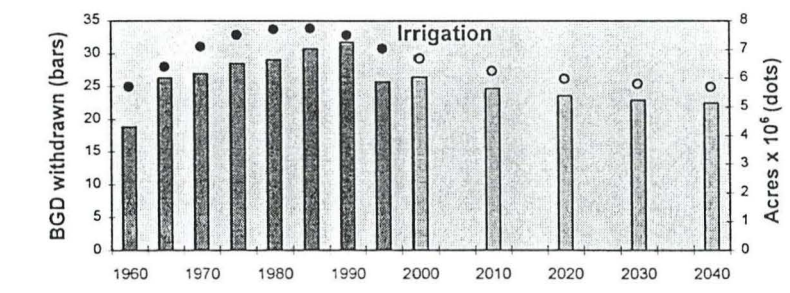
Pacific Northwest (WRR 17)











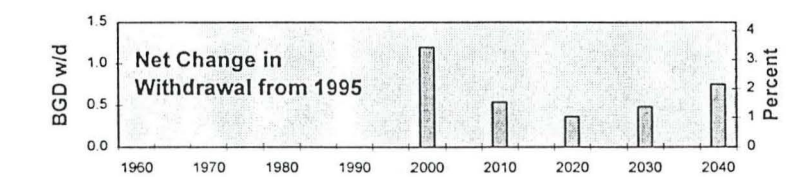


Fig. 25.18

California (WRR 18)

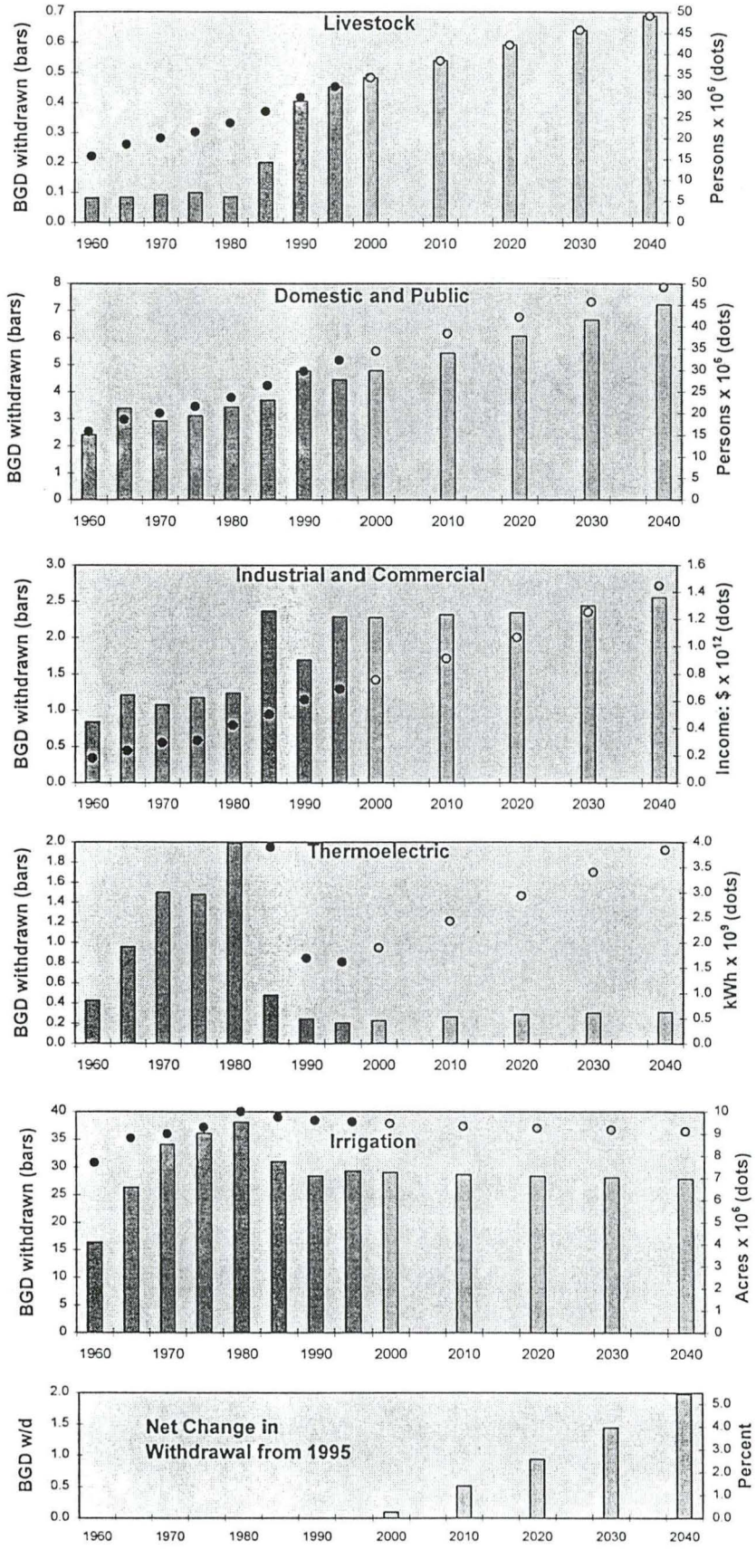
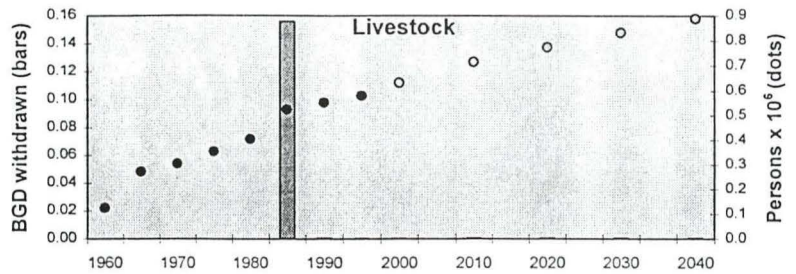
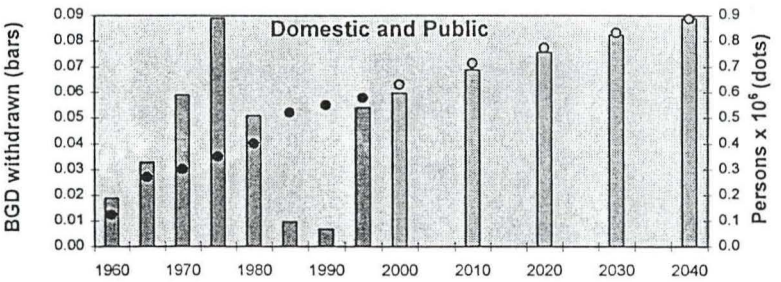
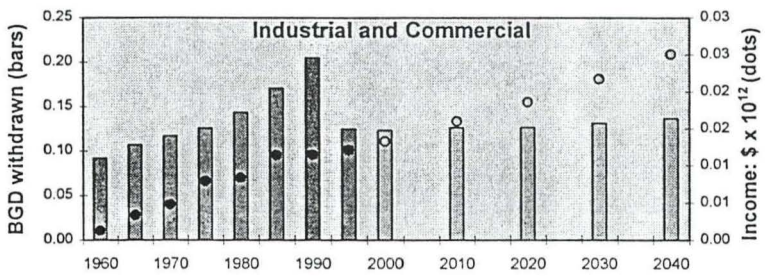


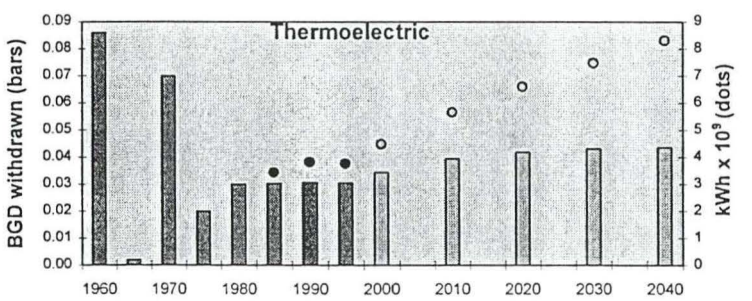
Fig. 25.19

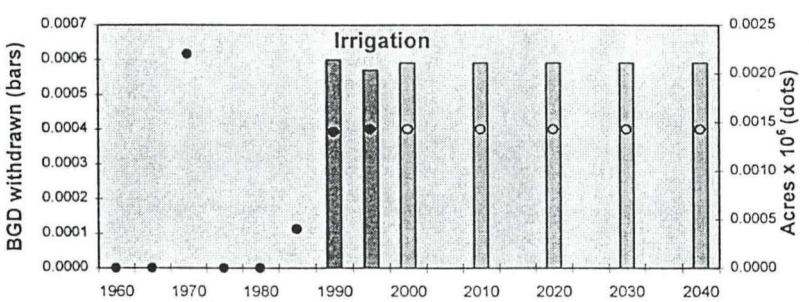
Alaska (WRR 19)











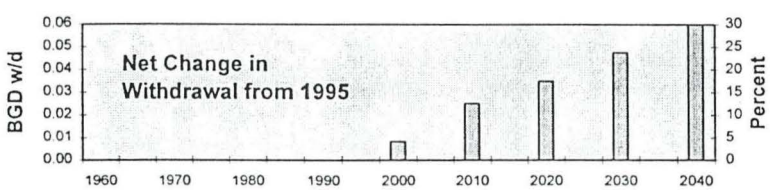
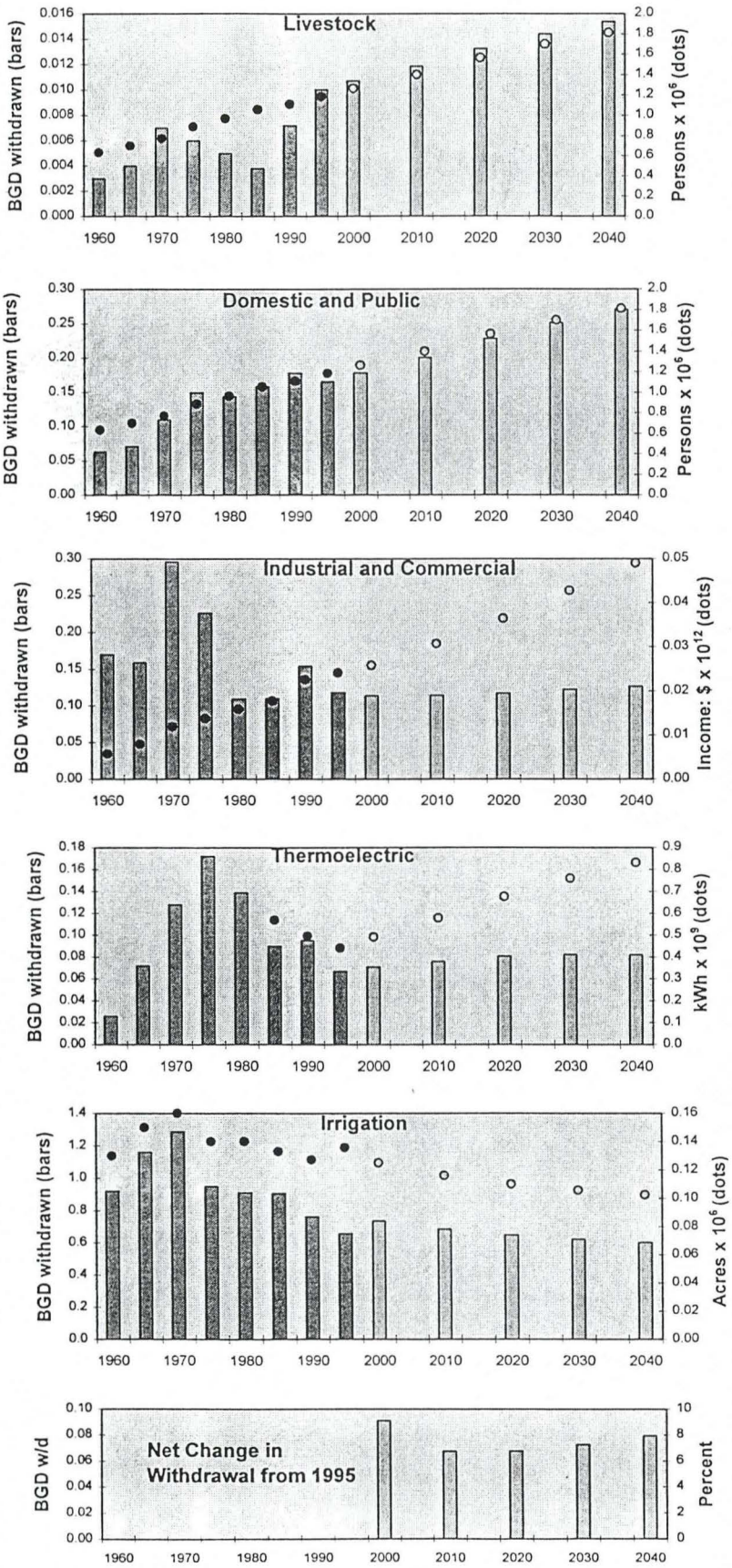


Fig. 25.20

Hawaii (WRR 20)